Central aortic versus axillary artery cannulation for aortic arch surgery

Megan M. Chung, BA,[a] Kerry Filtz, MD,[b] Michael Simpson, MD,[a] Samantha Nemeth, MS, MA, MPH,[c] Yaagnik Kosuri, MD,[a] Paul Kurlansky, MD,[c] Virendra Patel, MD, MPH,[a] and Hiroo Takayama, MD, PhD[a]

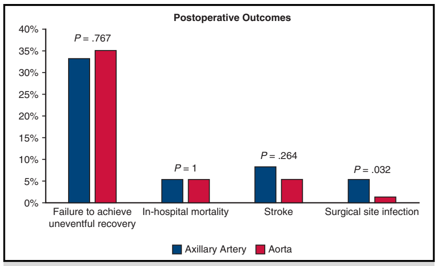
ABSTRACT

Objective: Central aortic cannulation for aortic arch surgery has become more popular over the last decade; however, evidence comparing it with axillary artery cannulation remains equivocal. This study compares outcomes of patients who underwent axillary artery and central aortic cannulation for cardiopulmonary bypass during arch surgery.

Methods: A retrospective review of 764 patients who underwent aortic arch surgery at our institution between 2005 and 2020 was performed. The primary outcome was failure to achieve uneventful recovery, defined as having experienced at least 1 of the following: in-hospital mortality, stroke, transient ischemic attack, bleeding requiring reoperation, prolonged ventilation, renal failure, mediastinitis, surgical site infection, and pacemaker or implantable cardiac defibrillator implantation. Propensity score matching was used to account for baseline differences across groups. A subgroup analysis of patients undergoing surgery for aneurysmal disease was performed.

Results: Before matching, the aorta group had more urgent or emergency operations ($P = .039$), fewer root replacements ($P < .001$), and more aortic valve replacements ($P < .001$). After successful matching, there was no difference between the axillary and aorta groups in failure to achieve uneventful recovery, 33% versus 35% ($P = .766$), in-hospital mortality, 5.3% versus 5.3% ($P = 1$), or stroke, 8.3% versus 5.3% ($P = .264$). There were more surgical site infections in the axillary group, 4.8% versus 0.4% ($P = .008$). Similar results were seen in the aneurysm cohort with no differences in postoperative outcomes between groups.

Conclusions: Aortic cannulation has a safety profile similar to that of axillary arterial cannulation in aortic arch surgery. (JTCVS Open 2023;14:14-25)



No difference in outcomes between aortic and axillary cannulation for aortic arch surgery.

CENTRAL MESSAGE

Evidence comparing aortic and axillary arterial cannulation for aortic arch surgery remains equivocal. Our study shows aortic cannulation has a similar safety profile to axillary arterial cannulation.

PERSPECTIVE

Although the aorta remains the standard cannulation site for cardiac surgery, axillary cannulation has become more popular for aortic surgery. Although axillary and aortic cannulation allow for ACP during aortic arch procedure, data comparing these methods are sporadic. Our study compares these methods and supports similar morbidity and mortality for aortic and axillary cannulation.

Arterial cannulation for aortic arch surgery requires special considerations for cardiopulmonary bypass because of the need for circulatory arrest and cerebral protection. Although the femoral artery remains a viable option, it may be associated with retrograde cerebral atheroembolism as well as organ malperfusion and creation of distal reentry tears in aortic dissections.[1-4] Since the early 1990s, axillary arterial cannulation has become more popular because of the advantage of antegrade cerebral perfusion (ACP); however, it comes at the cost of an additional surgical

From the [a]Division of Cardiothoracic and Vascular Surgery, and [c]Center for Innovation and Outcomes Research, New York-Presbyterian Hospital, Columbia University Irving Medical Center, New York, NY; and [b]Columbia University Vagelos College of Physicians and Surgeons, New York, NY.

Institutional Review Board Approval: AAAR2949 first approved August 10, 2017, most recently approved December 14, 2021. Informed Consent: Institutional Review Board approved waiver of consent.

Read at the 102nd Annual Meeting of The American Association for Thoracic Surgery, Boston, Massachusetts, May 14-17, 2022.

Received for publication May 14, 2022; revisions received Jan 23, 2023; accepted for publication Jan 27, 2023; available ahead of print February 25, 2023.

Address for reprints: Hiroo Takayama, MD, PhD, Division of Cardiac, Thoracic, and Vascular Surgery, Columbia University Medical Center, 177 Fort Washington Ave, New York, NY 10019 (E-mail: ht2225@cumc.columbia.edu).

2666-2736

https://doi.org/10.1016/j.xjon.2023.01.017

Abbreviations and Acronyms

ACP = antegrade cerebral perfusion
FUR = failure to achieve uneventful recovery
SMD = standardized mean difference
SSI = surgical site infection
TIA = transient ischemic attack

To view the AATS Annual Meeting Webcast, see the URL next to the webcast thumbnail.

incision, procedure, and risk of brachial plexus injury.[5-7] Nonetheless, its clinical utility has led to a wider application of this technique in a variety of aortic arch procedures, including dissections and aneurysms.[2,5,6]

Compared with deep hypothermic circulatory arrest, ACP is now considered the superior method.[8,9] Similar to axillary artery cannulation, ACP is possible with central aortic cannulation.[10-13] Aortic cannulation is advantageous because it is the most commonly used cannulation site for cardiac surgery and requires no additional incision or procedural steps. However, the role of central aortic cannulation in arch surgery has not been well understood because literature is sporadic with existing data limited to acute type A dissections.[10,14,15] Evidence comparing axillary and central cannulation techniques is scarce, and identification of an optimal cannulation site for all patients undergoing aortic arch operations remains challenging because of variations in individual anatomy and pathology. A better understanding of outcomes related to each cannulation site may better inform surgeons.

This study compares outcomes of ACP with central aortic or axillary arterial cannulation for patients undergoing aortic arch operations at a single tertiary-care academic medical center.

PATIENTS AND METHODS

Study Design and Patient Selection

This study was reviewed and approved (12/14/2021) by the Columbia University Medical Center Institutional Review Board (AAAR2949) with waiver of consent. This study was a single-center retrospective review of the Columbia University Aortic Center Database at New York-Presbyterian Hospital. All patients who underwent aortic arch surgery between January 2005 and December 2020 were included (n = 967). Patients were included if their surgery involved any segment of the aortic arch regardless of the proximal or distal extent of the surgery. Patients who underwent cannulation at a site other than the axillary artery or aorta (n = 102) and patients who had undergone a previous aortic arch surgery (n = 101) were excluded, resulting in a final cohort of 764 patients. For reoperative aortic arch surgery, central aortic cannulation was used whenever safe access to the ascending aorta or arch was feasible. Otherwise, axillary cannulation was performed. These patients are more frequently cannulated via the axillary artery at our center. Given a concern for a selection bias introduced by this strategy, reoperative aortic operations were excluded. This final cohort was then divided into 2 groups based on the site of arterial cannulation: axillary (n = 477) and aorta (n = 287). Propensity score matching was performed using variables listed in Tables 1 and 2 with a final matched cohort of axillary: n = 228, aorta: n = 228 (Figure 1).

Baseline patient characteristics, operative details, and postoperative complications were collected from the Columbia University Aortic Center Database. Whenever able, complications were defined on the basis of the Society of Thoracic Surgeons Adult Cardiac Database Version 2.9. Follow-up data were acquired retrospectively using electronic medical record review between 2005 and 2016, and prospectively after 2017 per our Aortic Center protocol. The Aortic Center database was queried to obtain follow-up information through scheduled postoperative visits at 1 month, 6 months, and annually. Additional information was gained through periodic contact with patients and referring cardiologists per center protocol to help capture events at outside institutions. No variables had more than 2% of missing data. The imputation of missing values is shown in Table E1.

The primary end point was failure to achieve uneventful recovery (FUR), defined per our previous study as experiencing any of the following postoperative complications: in-hospital mortality, stroke, transient ischemic attack (TIA), bleeding requiring reoperation, prolonged ventilation, renal failure, deep sternal wound infection, superficial surgical site infection (SSI), and pacemaker or implantable cardiac defibrillator implantation.[16] The outcomes comprising FUR are linked with long-term survival in our group's previous work. Occurrences of each of these complications were compared as secondary end points.

Patient Management

The site of arterial cannulation was at the discretion of the attending surgeon based on preference, patient anatomy, and pathology, and incidence of site varied as such (Figure E1). Axillary cannulation was performed through a 10-mm graft sewn to the axillary artery. The technique for central cannulation was determined by the attending surgeon. For aortic dissection, our institution routinely assures true lumen cannulation with epiaortic ultrasound-guided Seldinger cannulation. For aneurysm repair, direct cannulation is the standard. Surgical indication was determined by the attending surgeon, based on most recent American Heart Association, American College of Cardiology, and European Society of Cardiology Guidelines.[17] For aortic root replacement, the aortic valve was spared with reimplantation technique whenever appropriate, as previously described.[18-21] When replacement was necessary, the prosthetic valve was chosen based on American Heart Association/American College of Cardiology and European Society of Cardiology Guidelines as well as patient preference.

Management of cardiopulmonary bypass was standard for our study period. Our institution's standard surgical management has been recently described by Yamabe and colleagues.[18] Preoperatively, the cannulation and cerebral protection strategies were discussed with both the anesthesiology and perfusion teams to address any potential concerns. Our institution has experienced anesthesia and perfusion teams who are aware of these routine strategies and are able to implement them as needed. Standard bypass parameters were mild hypothermia (32 °C) with a pump flow rate of 2.5 mL/cm^2 and goal mean arterial pressure of 60 to 80 mm Hg. Distal aortic anastomosis for arch replacement was performed under moderate hypothermia (24 °C for total arch replacement and 28 °C for hemiarch replacement, nasopharyngeal) and ACP. Distal systemic perfusion, including renal perfusion, was temporarily halted until completion of the distal aortic anastomosis. Systemic perfusion was restarted with the side arm of the aortic graft.[22] For hemiarch replacement, unilateral ACP through the innominate artery or axillary artery was performed unless near-infrared spectroscopy showed decreased oxygen saturation in the

TABLE 1. Baseline patient characteristics

	Unmatched				Matched			
	Axillary (N = 477)*	Aorta (N = 287)*	*P* value†	SMD‡	Axillary (N = 228)*	Aorta (N = 228)*	*P* value†	SMD‡
Age	65.0 [53.0-74.0]	64.0 [54.0-73.0]	.635	0.037	65.0 [53.0-73.0]	64.0 [54.0-73.3]	.975	0.003
Female sex	136 (28.5)	82 (28.6)	1	0.001	64 (28.1)	64 (28.1)	1	<0.001
BMI	27.4 [24.6-31.1]	27.5 [24.9-31.7]	.477	0.067	27.5 [24.9-31.6]	27.7 [25.0-31.6]	.984	0.002
Diabetes	58 (12.2)	40 (13.9)	.548	0.053	26 (11.4)	27 (11.8)	1	0.014
Dyslipidemia	229 (48.0)	163 (56.8)	.023	0.177	133 (58.3)	125 (54.8)	.508	0.071
Dialysis	2 (0.4)	4 (1.4)	.205	0.103	1 (0.4)	1 (0.4)	1	<0.001
Hypertension	354 (74.2)	221 (77.0)	.436	0.065	180 (78.9)	177 (77.6)	.820	0.032
PVD	76 (15.9)	61 (21.3)	.078	0.137	48 (21.1)	50 (21.9)	.909	0.021
Previous MI	30 (6.3)	18 (6.3)	1	0.001	12 (5.3)	14 (6.1)	.840	0.038
LVEF	55.0 [50.0-55.0]	55.0 [53.0-60.0]	<.001	0.264	55.0 [54.0-55.0]	55.0 [50.0-58.0]	.161	0.027
Aortic insufficiency	254 (53.2)	132 (46.0)	.062	0.146	112 (49.1)	112 (49.1)	1	<0.001
Aortic stenosis	83 (17.4)	68 (23.7)	.043	0.156	43 (18.9)	46 (20.2)	.813	0.033
CVD	45 (9.4)	28 (9.8)	.984	0.011	22 (9.6)	25 (11.0)	.758	0.043
Creatinine	1.0 [0.9-1.2]	1.0 [0.1-1.1]	.404	0.021	1.0 [0.1-1.1]	1.0 [0.9-1.1]	.576	0.024
COPD	49 (10.3)	33 (11.5)	.682	0.039	25 (11.0)	20 (8.8)	.530	0.074
Marfan disease	3 (0.6)	2 (0.7)	1	0.008	2 (0.9)	2 (0.9)	1	<0.001
Surgical indication			.087	0.214			.731	0.074
Aneurysm	311 (65.2)	199 (69.3)			151 (66.2)	156 (68.4)		
Dissection	135 (28.3)	61 (21.3)			63 (27.6)	56 (24.6)		
Valvular dysfunction	25 (5.2)	22 (7.7)			14 (6.1)	16 (7.0)		
Intramural hematoma	0 (0.0)	1 (0.3)			0 (0.0)	0 (0.0)		
Infective endocarditis	5 (1.0)	2 (0.7)			0 (0.0)	0 (0.0)		
Other	1 (0.2)	2 (0.7)			0 (0.0)	0 (0.0)		
Stanford dissection			.171	0.186			.889	0.077
Acute type A	117 (24.5)	51 (17.8)			52 (22.8)	47 (20.6)		
Chronic type A	12 (2.5)	6 (2.1)			8 (3.5)	6 (2.6)		
Acute type B	1 (0.2)	0 (0.0)			0 (0.0)	0 (0.0)		
Chronic type B	5 (1.0)	4 (1.4)			3 (1.3)	3 (1.3)		
Urgent or emergency	153 (32.1)	114 (39.7)	.039	0.160	80 (35.1)	75 (32.9)	.693	0.046

SMD, Standardized mean difference; *BMI*, body mass index; *PVD*, peripheral vascular disease; *MI*, myocardial infarction; *LVEF*, left ventricular ejection fraction; *CVD*, cerebral vascular disease; *COPD*, chronic obstructive pulmonary disease. *n (%); median (interquartile range [IQR]). †*P* value < .05 indicates significance. ‡SMD < 0.10 indicates successful matching.

left head, in which case a left carotid artery catheter was added for bilateral cerebral perfusion. ACP was dosed at 8 to 12 mL/kg/min and was provided via the axillary cannula with a clamp applied at the base of the innominate artery or via direct cannulation of the ostia of the innominate or left common carotid arteries in the arch with balloon-tip catheters. With central aortic cannulation, upon cessation of systemic perfusion, a short period of retrograde cerebral perfusion via superior vena cava cannula was instituted to prevent air embolism upon institution of ACP. This retrograde cerebral perfusion period lasts 1 to 2 minutes while the surgeon resects the distal aorta and exposes the ostia of the innominate and left common carotid arteries for direct cannulation. The aortic cannula was removed, and a balloon-tip catheter was inserted into the innominate artery, followed by initiation of unilateral cerebral perfusion and cessation of retrograde cerebral perfusion. Bilateral cerebral perfusion was used for partial or total arch replacements.[23] The cerebral vasculature was de-aired using brief retrograde cerebral perfusion when cannulated centrally. The supra-aortic vessels were individually reconstructed using a multi-branch graft.

Statistical Analysis

The ‘car,’ ‘MatchIt,’ ‘dplyr’, ‘ggplot2,’ and ‘tableone’ packages of R statistical software (version 4.0.5, R Foundation) were used for statistical analysis and all figures. Data are expressed as frequencies and percentages for categorical variables. Continuous variables are expressed as mean (standard deviation) or median (interquartile range) depending on normality, which was tested via the Shapiro–Wilk test, and were compared using the *t* test or Mann–Whitney test, respectively. Categorical variables were compared using the chi-square or Fisher exact test depending on size (>5). Logistic regression was performed with cannulation site as the dependent variable and all patient characteristics and operative detail variables in Tables 1 and 2 as independent variables (Table E2). Variables in the model were checked for collinearity using the Variance Inflation Factor. No variables were found to be highly correlated (Variance Inflation Factor > 5).

Next, propensity score matching was performed with cannulation site as the dependent variables and the same variables from Tables 1 and 2 as the

TABLE 2. Operative details

	Unmatched				Matched			
	Axillary (N = 477)*	Aorta (N = 287)*	P value†	SMD‡	Axillary (N = 228)*	Aorta (N = 228)*	P value†	SMD‡
Root replacement	303 (63.5)	134 (46.7)	<.001	0.343	116 (50.9)	119 (52.2)	.851	0.026
Concomitant AVR	135 (28.3)	122 (42.5)	<.001	0.300	89 (39.0)	87 (38.2)	.923	0.018
Concomitant mitral or tricuspid valve replacement	21 (4.4)	5 (1.7)	.062	0.155	8 (3.5)	5 (2.2)	.575	0.079
Concomitant CABG	74 (15.5)	55 (19.2)	.228	0.097	46 (20.2)	43 (18.9)	.813	0.033
Partial/total arch replacement	192 (40.3)	131 (45.6)	.166	0.109	95 (41.7)	100 (43.9)	.705	0.044
Cardiopulmonary bypass time (min)	139 [109-176]	176 [140-209]	<.001	NA§	143 [109-178]	174 [141-212]	<.001	NA
Aortic crossclamp time (min)	91 [65-121]	118 [84-153]	<.001	NA	91 [65-123]	126 [87-157]	<.001	NA

SMD, Standardized mean difference; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *NA*, not available. *n (%). †*P* value < .05 indicates significance. ‡SMD < 0.10 indicates successful matching. §Indicates variable was not used in matching.

independent variables in the model. Patients were matched at a 1:1 ratio for axillary:aorta, and a 0.2 caliper was used. The caliper is the number of standard deviations of logit of the propensity score and used as a cutoff point in determining matches. Matching success was determined via standardized mean difference (SMD) less than 0.1 on variables postmatch. Matched groups were compared via the chi-square test.

Analyses on a subset of patients with a surgical indication of aneurysm were performed. Patients were similarly matched at a 1:1 ratio for axillary:aorta, and a 0.2 caliper was used on all variables shown in Tables 3 and 4. Surgical indication, Stanford classification, concomitant mitral or tricuspid valve replacement, concomitant coronary artery bypass grafting, and dialysis were removed from the match because of the smaller sample size's restraints on the number of variables the matching algorithm could handle. Surgical indication and Stanford classification were removed on the basis of the subset including only patients with aneurysm, and dialysis was removed because there were no events in the aneurysm subset. Matching success was again with an SMD less than 0.1. Matched groups were compared via the chi-square test.

RESULTS

Baseline Patient Characteristics and Operative Details

All baseline patient characteristics and operative details for the unmatched and matched cohorts are listed in Tables 1 and 2. The unmatched cohort had a median age of 64 years, and 28.5% were female. A greater proportion of patients in the aorta group had dyslipidemia (axillary: 48.0% [229/477], aorta: 56.8% [163/287]; *P* = .023) and aortic stenosis (axillary: 17.4% [83/477], aorta: 23.7% [68/287]; *P* = .043). Patients in the aorta group also had a slightly higher left ventricular ejection fraction (axillary: 55.0 [50.0-55.0], aorta: 55.0 [53.0-60.0]; *P* < .001), which is unlikely to be clinically significant. Before matching, there were no other differences in baseline patient charac-

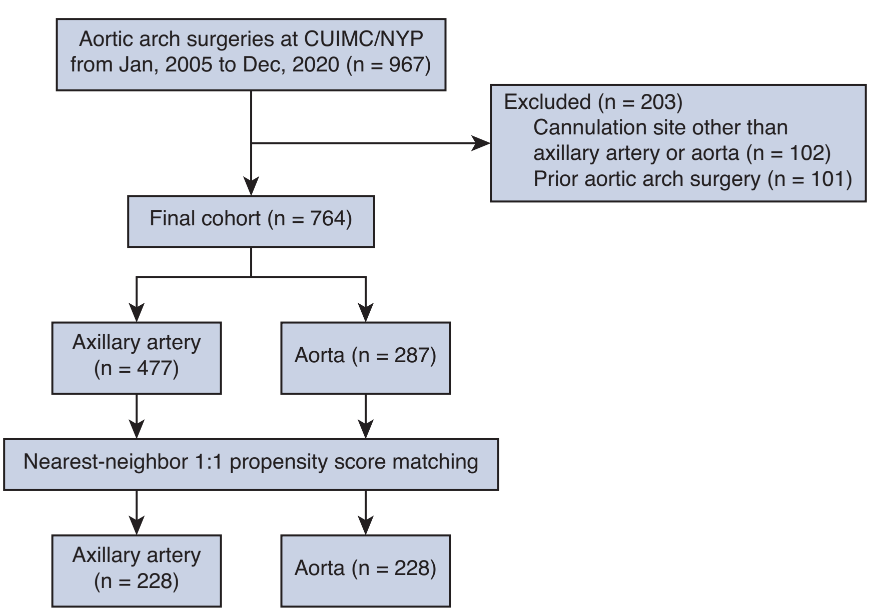


FIGURE 1. CONSORT diagram. *CUIMC/NYP*, Columbia University Irving Medical Center/New York-Presbyterian.

TABLE 3. Aneurysm subgroup baseline patient characteristics

	Unmatched				Matched			
	Axillary (N = 311)*	Aorta (N = 199)*	*P* value†	SMD‡	Axillary (N = 150)*	Aorta (N = 150)*	*P* value†	SMD‡
Age	65.0 [53.0-73.0]	63.0 [55.0-73.0]	.702	0.026	65.0 [52.3-72.8]	64.0 [55.3-73.0]	.705	0.025
Female sex	86 (27.7)	56 (28.1)	.985	0.011	36 (24.0)	35 (23.3)	1	0.016
BMI	27.3 [24.9-30.7]	27.5 [24.9-31.6]	.491	0.075	27.6 [25.4-31.0]	27.1 [24.6-30.8]	.629	0.030
Diabetes	32 (10.3)	24 (12.1)	.632	0.056	16 (10.7)	17 (11.3)	1	0.021
Dyslipidemia	146 (46.9)	114 (57.3)	.029	0.208	85 (56.7)	81 (54.0)	.728	0.054
Hypertension	222 (71.4)	146 (73.4)	.699	0.044	112 (74.7)	111 (74.0)	1	0.015
PVD	45 (14.5)	41 (20.6)	.092	0.162	29 (19.3)	33 (22.0)	.669	0.066
Previous MI	18 (5.8)	11 (5.5)	1	0.011	7 (4.7)	8 (5.3)	1	0.031
LVEF	55.0 [50.0-55.0]	55.0 [53.5-60.0]	<.001	0.230	55.0 [50.0-55.0]	55.0 [50.3-58.75]	.109	0.069
Aortic insufficiency	166 (53.4)	87 (43.7)	.042	0.194	77 (51.3)	70 (46.7)	.488	0.093
Aortic stenosis	68 (21.9)	55 (27.6)	.167	0.134	31 (20.7)	36 (24.0)	.579	0.080
CVD	28 (9.0)	15 (7.5)	.676	0.053	14 (9.3)	13 (8.7)	1	0.023
Creatinine	1.0 [0.9-1.1]	1.0 [0.8-1.1]	.257	0.153	1.0 [0.9-1.1]	1.0 [0.9-1.1]	.857	0.033
COPD	31 (10.0)	23 (11.6)	.673	0.051	17 (11.3)	16 (10.7)	1	0.021
Marfan disease	2 (0.6)	2 (1.0)	.645	0.040	1 (0.7)	1 (0.7)	1	<0.001
Urgent or emergency	24 (7.7)	53 (26.6)	<.001	0.518	24 (16.0)	23 (15.3)	1	0.018

SMD, Standardized mean difference; *BMI*, body mass index; *PVD*, peripheral vascular disease; *MI*, myocardial infarction; *LVEF*, left ventricular ejection fraction; *CVD*, cerebral vascular disease; *COPD*, chronic obstructive pulmonary disease. *n (%); median [IQR]. †*P* value less than .05 indicates significance. ‡SMD < 0.10 indicates successful matching

teristics between the groups, including age, gender, body mass index, diabetes, dialysis, hypertension, peripheral vascular disease, previous myocardial infarction, aortic insufficiency, cerebral vascular disease, creatinine, chronic obstructive pulmonary disease, and Marfan disease. In the unmatched cohort, surgical indication was aneurysmal disease in 66.8% (510/764), dissection in 25.7% (196/764), and valvular dysfunction in 6.2% (47/764). Of those undergoing aortic dissection repair, 85.7% (168/196) had acute type A dissection. These variables did not differ across groups; however, there were more urgent or emergency surgeries in the aorta group (axillary: 32.1% [153/477], aorta: 39.7% [114/287]; $P = .039$).

There were fewer root replacements in the aorta group (axillary: 63.5% [303/477], aorta: 46.7% [134/287], $P < .001$) and more concomitant aortic valve replacements in the aorta group (axillary: 28.3% [135/477], aorta: 42.5% [122/287], $P < .001$). There were no differences between the groups in concomitant coronary artery bypass grafting or concomitant mitral or tricuspid valve surgery. Extent of aortic replacement categorized as partial or total arch replacement compared with hemiarch replacement also did not differ between the groups (overall: 42.3% [323/764]) compared with hemiarch replacement (overall: 57.7% [441/764]).

Median and interquartile range cardiopulmonary bypass times in the axillary and aorta groups were 139 [109-176] minutes and 176 [140-209] minutes, respectively, in the unmatched cohort, and 143 [109-178] minutes and 174 [141-212] minutes, respectively, after matching ($P < .001$). The axillary group had shorter aortic crossclamp times (unmatched: 91 [65-121] vs 118 [84-153]; matched: 91 [65-123] vs 126 [87-157]) and ACP times (unmatched: 12 [10-16] vs 17 [9-24]; matched: 12 [10-17] vs 17 [10-25]) ($P < .001$).

Postoperative Outcomes

Propensity score matching was successful as evidenced by an SMD less than 0.1 for each matched variable. Results of matching are displayed in Tables 1 and 2. Postoperative outcomes for the unmatched and matched cohorts are displayed in Table 5. There was no difference in the primary outcome of FUR across groups in the matched cohort (axillary: 32.9% [75/228], aorta: 34.6% [79/228]; $P = .766$). Furthermore, there was no difference in each of the individual outcomes included in FUR except SSI. SSIs occurred in 4.8% (11/228) of patients in the axillary group, with 8 in the sternum or mediastinum and 3 at sites from vascular operations during the same hospital stay; there were no SSIs at axillary cannulation sites in the entire cohort. There was 1 SSI in the aorta group at a saphenous vein cutdown (0.4%, $P = .008$). Stroke occurred in 8.3% (19/228) of patients in the axillary group and 5.3% (12/228) of patients in the aorta group ($P = .264$), whereas TIA occurred in 3.9% (9/228) of patients in the axillary group and 1.3% (3/228) of patients in the aorta group ($P = .141$). In-hospital mortality was 5.3% (12/228) in the axillary group and 5.3% (12/228) in the aorta group ($P = 1$). The most common complication was prolonged ventilation, which occurred in 16.2% (37/228) of patients in the axillary group and 21.9% (50/228) of patients in the aorta group ($P = .153$).

TABLE 4. Aneurysm subgroup operative details

	Unmatched				Matched			
	Axillary (N = 311)*	Aorta (N = 199)*	P value†	SMD‡	Axillary (N = 150)*	Aorta (N = 150)*	P value†	SMD‡
Root replacement	217 (69.8)	100 (50.3)	<.001	0.407	84 (56.0)	85 (56.7)	1	0.013
Concomitant AVR	85 (27.3)	88 (44.2)	<.001	0.358	58 (38.7)	54 (36.0)	.720	0.055
Partial/total arch replacement	114 (36.7)	87 (43.7)	.134	0.144	59 (39.3)	62 (41.3)	.814	0.041

SMD, Standardized mean difference; *AVR*, aortic valve replacement. *n (%). †$P < .05$ indicates significance. ‡SMD < 0.10 indicates successful matching.

Subgroup Analysis

A subgroup analysis for patients undergoing an operation for aneurysm was performed with a cohort of axillary (n = 311, aorta: n = 199) before matching and a matched cohort of axillary (n = 150, aorta: n = 150). Baseline patient characteristics and operative details for both the matched and unmatched cohorts are shown in Tables 3 and 4. In the unmatched aneurysm cohort, there were higher rates of dyslipidemia in the aorta group (axillary: 46.9% [146/311], aorta: 57.3% [114/199]; $P = .029$), slightly higher left ventricular ejection fraction in the aorta group (axillary: 55.0 [50.0-55.0], aorta; 55.0 [53.5-60.0]; $P < .001$), and lower rates of aortic insufficiency in the aorta group (axillary: 53.4% [166/311], aorta: 43.7% [87/199]; $P = .042$). There were also more urgent or emergency cases in the aorta group (axillary: 7.7% [24/311], aorta: 26.6% [53/199]; $P < .001$), fewer root replacements in the aorta group (axillary: 69.8% [217/311], aorta: 50.3% [100/199]; $P < .001$), and more concomitant aortic valve replacements in the aorta group (axillary: 27.3% [85/311], aorta: 44.2% [88/199]; $P < .001$).

Postoperative outcomes for the unmatched and matched aneurysm subgroup are shown in Table 6. After matching, there were no differences in the primary outcome of FUR (axillary: 29.3% [44/150], aorta: 28.0% [42/150]; $P = .898$) or in-hospital mortality (axillary: 4.0% [6/150], aorta: 4.0% [6/150], $P = 1$) across groups. There were also no differences in any of the individual outcomes included in FUR across groups in the matched aneurysm cohort.

DISCUSSION

Cannulation strategy is an important element of operative planning for aortic arch operations, and there is a need for more data on the relative safety of different cannulation strategies. This is especially true for axillary and aortic cannulation, which have grown in popularity in recent decades. Aortic cannulation in a diseased aorta may raise concerns for its safety, namely, iatrogenic dissection or rupture.[24,25] We have previously reported an incidence of iatrogenic aortic dissection of 0.06% (15/23,275). Of those who experienced a dissection, 33.3% were undergoing surgery for aneurysmal disease, and notably, most dissections (66.7%) occurred at the time of aortic cannulation.[26] Hwang and colleagues[24] reported an incidence of iatrogenic aortic dissection of 0.29% (10/3421) among cardiac surgical patients; the most common cannulation site in these dissections was the ascending aorta. Although the reported incidence of this complication remains low, mortality has been reported as high as 30% to 40% and therefore merits further investigation.[24,27]

In this large, retrospective cohort study of patients who received aortic arch operations at an urban tertiary care center, there was no difference in the likelihood of uneventful recovery between those who underwent central aortic cannulation and those who underwent axillary arterial cannulation (Figure 2). There was an increased incidence of SSI in the axillary group, although interestingly, the SSIs were not associated with the cannulation site. Otherwise, there was no difference in the likelihood of complications, including stroke, TIA, prolonged ventilation, or in-hospital mortality between the 2 groups. There were no differences in postoperative outcomes in the subgroup of patients with aneurysm as their primary surgical indication.

Prior studies investigating cannulation strategy in aortic surgery have focused mainly on repair of aortic dissection or compared femoral cannulation with central aortic cannulation. Even among these studies with a narrower focus in terms of surgical indication, there is no consensus on preferred cannulation site. Kreibich and colleagues[12] found no difference in morbidity and mortality among central aortic, axillary, and femoral cannulation and found that cannulation site was not an independent predictor of in-hospital mortality. Reece and colleagues,[15] on the other hand, found lower rates of cardiac complications and mortality with central aortic cannulation compared with peripheral (femoral or axillary) cannulation. Studies on innominate artery cannulation have also proven its noninferiority in comparison with axillary cannulation in terms of overall clinical outcomes, including a recent high-quality randomized control trial by Peterson and colleagues[30] that demonstrated similar neuroprotection and new lesion burden in elective proximal arch surgery.[28-30] Finally, Sabashnikov and colleagues[15] found no difference in morbidity between central aortic and axillary cannulation but did find higher rates of early and late mortality with central aortic cannulation. The addition of our institution's data and expansion of these findings to include a variety of surgical indications is an important contribution to the existing literature.

TABLE 5. Postoperative outcomes

	Unmatched			Matched		
	Axillary (N = 477)*	Aorta (N = 287)*	P value†	Axillary (N = 228)*	Aorta (N = 228)*	P value†
Stroke	36 (7.5)	17 (5.9)	.479	19 (8.3)	12 (5.3)	.264
TIA	10 (2.1)	3 (1.0)	.390	9 (3.9)	3 (1.3)	.141
Reoperation for bleeding	38 (8.0)	23 (8.0)	1	13 (5.7)	17 (7.5)	.571
SSI	15 (3.1)	1 (0.3)	.019	11 (4.8)	1 (0.4)	.008
Renal failure	56 (11.7)	24 (8.4)	.176	22 (9.6)	21 (9.2)	1
Prolonged ventilation	82 (17.2)	65 (22.6)	.079	37 (16.2)	50 (21.9)	.153
Pacemaker or ICD	26 (5.5)	13 (4.5)	.696	11 (4.8)	13 (5.7)	.834
Postoperative LOS	8.0 [6.0-12.0]	8.0 [6.0-14.0]	.082	7.0 [6.0-12.0]	8.5 [6.0-15.0]	.065
In-hospital mortality	26 (5.5)	13 (4.5)	.696	12 (5.3)	12 (5.3)	1
FUR	161 (34.0)	100 (34.8)	.819	75 (32.9)	79 (34.6)	.766

TIA, Transient ischemic attack; *SSI*, surgical site infection; *ICD*, implantable cardiac defibrillator; *LOS*, length of stay; *FUR*, failure to achieve uneventful recovery. *n (%); median [IQR]. †*P* value < .05 indicates significance.

Our study showed an increased ACP time, bypass time, and aortic crossclamp time in aortic cannulation. With aortic cannulation, the surgical field becomes more complicated, requiring a cannula in the innominate artery and oftentimes the left carotid, leading to an increased ACP time. It is not clear why the crossclamp times and bypass times are longer; in the literature, one criticism of axillary cannulation is its requirement for an additional incision, time for dissection, and control of the axillary artery.[12] Some centers report that direct cannulation techniques limit the amount of required dissection, risk vascular injury, and may require distal perfusion catheters to prevent limb ischemia.[31] Nonetheless, we believe that the increased operative time of the aortic cannulation indirectly suggests the safety of the strategy, because outcomes are similar despite increased operative times.

Study Limitations

A limitation of this study includes our focus on short-term morbidity and in-hospital mortality. Sabashnikov and colleagues[13] found similar rates of early hospital outcomes and adverse events when comparing axillary and central aortic cannulation in their study of 235 patients undergoing aortic repair for acute type A dissection. However, they found higher rates of long-term mortality among patients who had undergone central aortic cannulation after performing propensity score matching.[13] The authors in this study acknowledge that it was at times difficult to assess the accuracy of the transesophageal echocardiogram used for confirmation of proper cannula placement, which might have contributed to the higher rates of malperfusion that were most often the cause of the multiorgan failure seen in patients with late-term mortality. Confirmation of true lumen cannulation for repair of type A aortic dissection is requisite. The use of techniques such as epiaortic ultrasound-guided or echocardiography-guided Seldinger technique or the Samurai technique has improved the safety of central cannulation in type A aortic dissection, and are the standard at our institution.[32,33]

TABLE 6. Aneurysm subgroup postoperative outcomes

	Unmatched			Matched		
	Axillary (N = 311)*	Aorta (N = 199)*	P value†	Axillary (N = 150)*	Aorta (N = 150)*	P value†
Stroke	19 (6.1)	9 (4.5)	.570	11 (7.3)	6 (4.0)	.318
TIA	7 (2.3)	2 (1.0)	.493	5 (3.3)	1 (0.7)	.214
Reoperation for bleeding	21 (6.8)	12 (6.0)	.890	10 (6.7)	8 (5.3)	.808
SSI	10 (3.2)	1 (0.5)	.081	4 (2.7)	1 (0.7)	.367
Renal failure	23 (7.4)	10 (5.0)	.381	15 (10.0)	8 (5.3)	.193
Prolonged ventilation	35 (11.3)	39 (19.6)	.013	21 (14.0)	29 (19.3)	.278
Pacemaker or ICD	18 (5.8)	3 (1.5)	.021	9 (6.0)	3 (2.0)	.138
Postoperative LOS	7.0 [5.0-10.0]	8.0 [5.0-12.0]	.032	7.0 [5.0-10.8]	8.0 [5.0-11.0]	.199
In-hospital mortality	10 (3.2)	7 (3.5)	1	6 (4.0)	6 (4.0)	1
FUR	85 (27.3)	58 (29.1)	.731	44 (29.3)	42 (28.0)	.898

TIA, Transient ischemic attack; *SSI*, surgical site infection; *ICD*, implantable cardiac defibrillator; *LOS*, length of stay; *FUR*, failure to achieve uneventful recovery. *n (%); median [IQR]. †*P* < .0045 indicates significance.

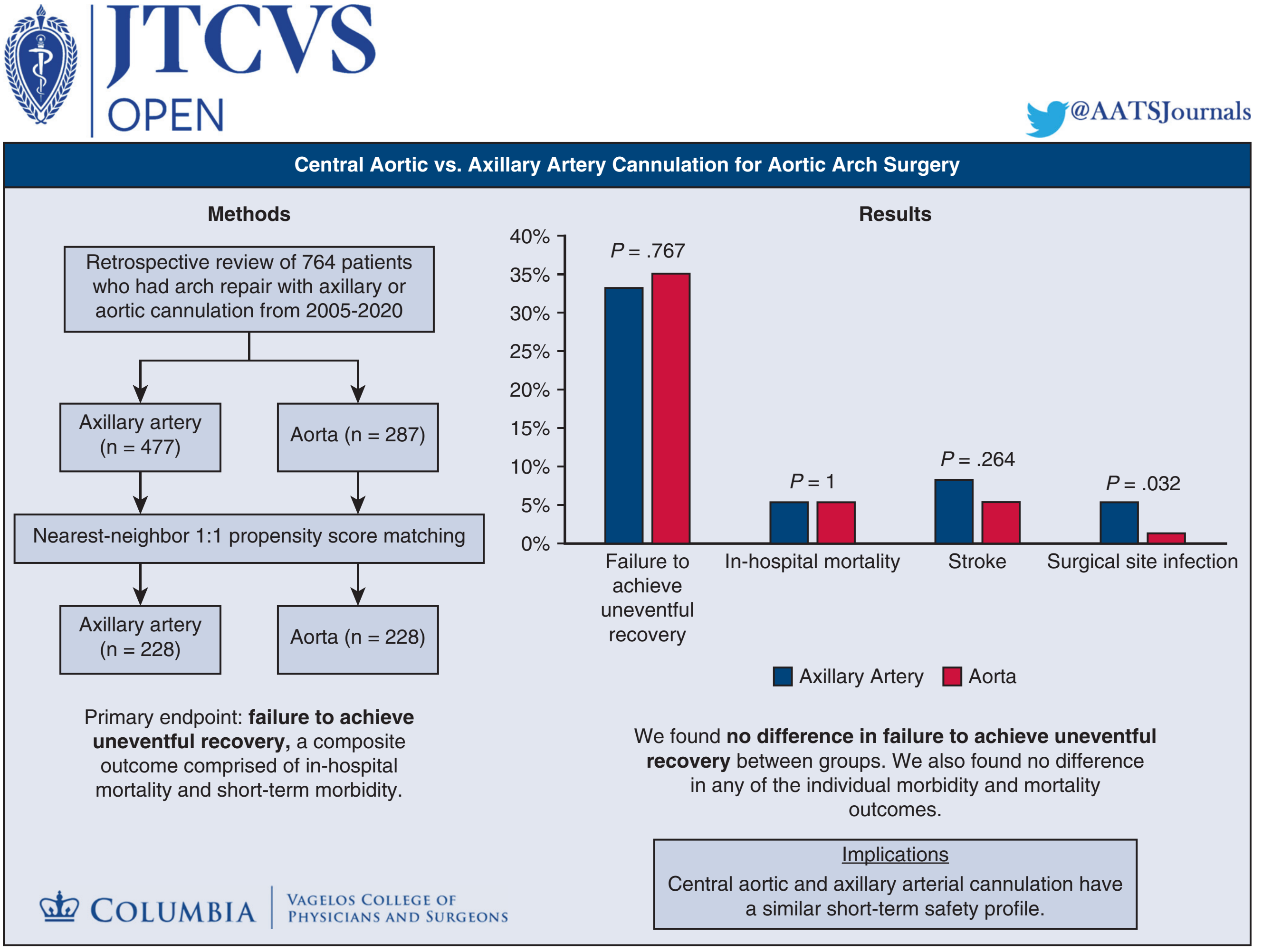


FIGURE 2. Visual Abstract.

Further limitations of our study derive from its nature as a retrospective database study. The use of axillary cannulation declined over our study period, with aortic cannulation becoming the predominant strategy in more recent times; this may lend to a subtle bias toward aortic cannulation because overall patient outcomes may have improved over time. Some granular case-by-case detail including specific cannulation technique (ie, Seldinger vs direct) or degree of aortic atherosclerosis is not included in our database. These details may have implications on postoperative complications, especially stroke and TIA. There is also no detailed information regarding brachial plexus injury, which may result from axillary artery dissection, although our previous study showed an extremely low rate of such complication.[22] Our study cannot account for this, but these are worthy of further investigation in future work.

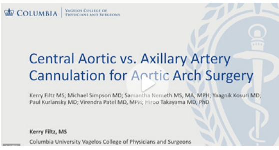
Despite the study's limitations, the findings add to existing literature in several ways. First, although previous research has compared aortic or axillary cannulation with femoral cannulation, there are comparatively little data comparing the safety of aortic and axillary cannulation to each other. Second, prior research on this subject has focused on patients with type A aortic dissection, whereas this study included a broader range of indications: aortic aneurysm, aortic dissection, valvular dysfunction, and infective endocarditis, and went a step further in performing a subgroup analysis of aneurysm patients to show that the safety of central aortic cannulation extends beyond the especially risky subgroup of patients with acute dissection.

CONCLUSIONS

This retrospective cohort analysis found no difference in safety between aortic and axillary cannulation strategies for aortic arch surgery and generates hypotheses for further investigation into specific subpopulations and long-term outcomes.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/1333.



Conflict of Interest Statement

H.T. is a consultant for Artivion and a speaker with Terumo. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

References

1. Westaby S, Katsumata T, Vaccari G. Arch and descending aortic aneurysms: influence of perfusion technique on neurological outcome. *Eur J Cardiothorac Surg*. 1999;15:180-5.
2. Gulbins H, Pritisanac A, Ennker J. Axillary versus femoral cannulation for aortic surgery: enough evidence for a general recommendation? *Ann Thorac Surg*. 2007;83:1219-24.
3. Reuthebuch O, Schurr U, Hellermann J, Prêtre R, Künzli A, Lachat M, et al. Advantages of subclavian artery perfusion for repair of acute type A dissection. *Eur J Cardiothorac Surg*. 2004;26:592-8.
4. Voci P, Testa G, Tritapepe L, Menichetti A, Caretta Q. Detection of false lumen perfusion at the beginning of cardiopulmonary bypass in patients undergoing repair of aortic dissection. *Crit Care Med*. 2000;28:1841-6.
5. Sabik JF, Lytle BW, McCarthy PM, Cosgrove DM. Axillary artery: an alternative site of arterial cannulation for patients with extensive aortic and peripheral vascular disease. *J Thorac Cardiovasc Surg*. 1995;109:885-91.
6. Strauch JT, Spielvogel D, Lauten A, Lansman SL, McMurtry K, Bodian CA, et al. Axillary artery cannulation: routine use in ascending aorta and aortic arch replacement. *Ann Thorac Surg*. 2004;78:103-8.
7. Schachner T, Nagiller J, Zimmer A, Laufer G, Bonatti J. Technical problems and complications of axillary artery cannulation. *Eur J Cardiothorac Surg*. 2005;27:634-7.
8. Hagl C, Ergin A, Galla J, Lansman SL, McCullough JN, Spielvogel D, et al. Neurologic outcome after ascending aorta–aortic arch operations: effect of brain protection technique in high-risk patients. *J Thorac Cardiovasc Surg*. 2001;121:1107-21.
9. Eusanio M, Wesselink R, Morshuis W, Dossche K, Schepens M. Deep hypothermic circulatory arrest and antegrade selective cerebral perfusion during ascending aorta-hemiarch replacement: a retrospective comparative study. *J Thorac Cardiovasc Surg*. 2003;125:849-54.
10. Minatoya K, Karck M, Szpakowski E, Harringer W, Haverich A. Ascending aortic cannulation for Stanford type A acute aortic dissection: another option. *J Thorac Cardiovasc Surg*. 2003;125:952-3.
11. Svensson L, Blackstone E, Rajeswaran J, Sabik JF, Lytle BW, Gonzalez-Stawinski G, et al. Does the arterial cannulation site for circulatory arrest influence stroke risk? *Ann Thorac Surg*. 2004;78:1274-84.
12. Kreibich M, Chen Z, Rylski B, Bavaria JE, Brown CR, Branchetti E, et al. Outcome after aortic, axillary, or femoral cannulation for acute type A aortic dissection. *J Thorac Cardiovasc Surg*. 2019;158:27-34.
13. Sabashnikov A, Heinen S, Deppe AC, Zeriouh M, Weymann A, Slottosch I, et al. Axillar or aortic cannulation for aortic repair in patients with Stanford A dissection? *Ann Thorac Surg*. 2016;102:787-94.
14. Lijoi A, Scarano F, Dottori V, Parodi E, Casali G, Bartolozzi F. Stanford type A aortic dissection. A new surgical approach. *Tex Heart Inst J*. 1998;25:65-7.
15. Reece TB, Tribble CG, Smith RL, Singh RR, Stiles BM, Peeler BB, et al. Central cannulation is safe in acute aortic dissection repair. *J Thorac Cardiovasc Surg*. 2007;133:428-34.
16. Yamabe T, Zhao Y, Sanchez J, Kelebeyev S, Bethancourt CNR, Mcmullen HL, et al. Probability of uneventful recovery after elective aortic root replacement for aortic aneurysm. *Ann Thorac Surg*. 2020;110:1485-93.
17. Mokashi SA, Svensson LG. Guidelines for the management of thoracic aortic disease in 2017. *Gen Thorac Cardiovasc Surg*. 2019;67:59-65.
18. Yamabe T, Zhao Y, Kurlansky PA, Nitta S, Borger MA, George I, et al. Assessment of long-term outcomes: aortic valve reimplantation versus aortic valve and root replacement with biological valved conduit in aortic root aneurysm with tricuspid valve. *Eur J Cardiothorac Surg*. 2021;59:658-65.
19. Bethancourt CN, Blitzer D, Yamabe T, Zhao Y, Nguyen S, Nitta S, et al. Valve-Sparing root replacement versus Bio-Bentall: inverse propensity weighting of 796 patients. *Ann Thorac Surg*. 2022;113:1529-35.
20. Nguyen SN, Yamabe T, Zhao Y, Kurlansky PA, George I, Smith CR, et al. Bicuspid-associated aortic root aneurysm: mid to long-term outcomes of David V versus the Bio-Bentall procedure. *Semin Thorac Cardiovasc Surg*. 2021;33:933-43.
21. Yamabe T, Eudailey KW, Jimenez OG, DeRoo S, Kurlansky PA, George I, et al. Double mattress suture lines for valve sparing aortic root replacement. *J Card Surg*. 2019;34:1344-6.
22. Takayama H, Smith CR, Bowdish ME, Stewart AS. Open distal anastomosis in aortic root replacement using axillary cannulation and moderate hypothermia. *J Thorac Cardiovasc Surg*. 2009;137:1450-3.
23. Fukuhara S, DeRoo S, Beck J, Takayama H. Facilitation of bilateral selective antegrade cerebral perfusion with axillary cannulation and retrograde coronary sinus catheter. *Perfusion*. 2015;30:495-8.
24. Hwang HY, Jeong DS, Kim KH, Kim KB, Ahn H. Iatrogenic type A aortic dissection during cardiac surgery. *Interact Cardiovasc Thorac Surg*. 2010;10:896-9.
25. Fleck T, Ehrlich M, Czerny M, Wolner E, Grabenwoger M, Grimm M. Intraoperative iatrogenic type A aortic dissection and perioperative outcome. *Interact Cardiovasc Thorac Surg*. 2006;5:11-4.
26. Shea NJ, Polanco AR, D'Angelo A, Bethancourt CN, Sanchez J, George I, et al. Improving outcomes of iatrogenic type A aortic dissection during cardiac surgery. *Aorta (Stamford)*. 2019;7:115-20.
27. Leontyev S, Borger MA, Legare JF, et al. Iatrogenic type A aortic dissection during cardiac procedures: early and late outcome in 48 patients. *Eur J Cardiothorac Surg*. 2012;41:641-6.
28. Preventza O, Price MD, Spiliotopoulos K, Amarasekara HS, Cornwell LD, Omer S, et al. In elective arch surgery with circulatory arrest, does the arterial cannulation site really matter? A propensity score analysis of right axillary and innominate artery cannulation. *J Thorac Cardiovasc Surg*. 2018;155:1953-60.e4.
29. Harky A, Grafton-Clarke C, Hadlett M, Shuttleworth E. In thoracic aortic surgery, is innominate artery cannulation a safe and effective alternative to axillary artery cannulation? *Interact Cardiovasc Thorac Surg*. 2019;29:604-7.
30. Peterson MD, Garg V, Mazer CD, Chu MWA, Bozinovski J, Dagenais F, Kinoshita T, Hiramatsu H, Nishimura O, et al; ACE CardioLink-3 Trial Working Group. A randomized trial comparing axillary versus innominate artery cannulation for aortic arch surgery. *J Thorac Cardiovasc Surg*. 2022;164:1426-38.e2.
31. Yilik L, Emrecan B, Kestelli M, Ozsoyler I, Lafci B, Yakut N, et al. Direct versus side-graft cannulation of the right axillary artery for antegrade cerebral perfusion. *Tex Heart Inst J*. 2006;33:310-5.
32. Kitamura T, Torii S, Kobayashi K, Tanaka Y, Sasahara A, Ohtomo Y, et al. Samurai cannulation (direct true-lumen cannulation) for acute Stanford Type A aortic dissection. *Eur J Cardiothorac Surg*. 2018;54:498-503.
33. Suzuki T, Asai T, Matsubayashi K, et al. Safety and efficacy of central cannulation through ascending aorta for type A aortic dissection. *Interact Cardiovasc Thorac Surg*. 2010;11:34-7.

Key Words: aortic arch surgery, arterial cannulation, cardiopulmonary bypass

Discussion

Presenter: Kerry Filtz

Dr Anthony Estrera *(Houston, Tex)*. My question, which I think is important, is related and goes back to one of the positives of Dr Keeling's study, and that study really defined how they managed temperature and measured it. I think a lot of articles nowadays don't really talk about that, because that's one important factor that should be mentioned and clearly defined in an article that talks about this topic. The fact that nasopharyngeal temperature was mentioned in this article, and that group had actually defined those different categories of hypothermia, profound deep hypothermia, and things like that. So, my first question relates to temperature management. How was that done in your study and how is it recorded?

Dr Kerry Filtz *(New York, NY)*. I do not know the answer to that question. But if I can, I'll defer to my mentor, is that okay?

Dr Estrera. Of course.

Dr Filtz. Okay.

Dr Hiroo Takayama (New York, NY). She prepared very well how to answer many questions, but that's the one thing that we did not [inaudible].

Dr Estrera. Well, that's your fault.

Unidentified Speaker 1. I know.

Dr Filtz. That's your fault.

Unidentified Speaker 1. Yeah. But, no, the temperature was maybe one of the variables we looked at. There was no difference. Our management has always been moderate hypothermia for hemiarch 28, total arch 24 to 28.

Dr Estrera. But how do you measure it? I think that's important.

Unidentified Speaker 1. So before until recently, until the last 4 or 5 years, we measured only nasopharyngeal. But currently, we measure nasopharyngeal and rectal temp.

Dr Estrera. I think that's an important point because if you really think about it, there are a lot of tools, a lot of things that we talk about or can watch during surgery. If you're going to do femoral cannulation, obviously, the bladder temperature is going to decrease quicker than the nasal. But as long as the nasal is decreasing, then I'm fine with that. But these are all these little clues, as a surgeon coming up that you have to really pay attention to during your operation. I think for the article, you guys didn't have it included. But I think operative time, if you have access to that data, it's just a suggestion. I would include that in the article because as we all know, the longer the pump time, I know your [inaudible] times were 20 minutes. Oh, actually, that was his article. That was your article. I can't remember. Anyway, yes. But the reality is that I think it's important to try to think if you guys can include that in your article.

Unidentified Speaker 1. She has a question for that.

Dr Estrera. Very good.

Dr Filtz. I do have an answer to that.

Dr Estrera. Okay, good.

Dr Filtz. That's a great point. We did think about that as well, especially after reading about operative times in different articles that we read. We tried to look for the operative times. Because of the retrospective nature of this, we couldn't get the skin-to-skin, which is what we were especially interested in for this. As far as other operative times, the sequence of the steps of the procedure have changed over time. To us, it made more sense that any differences in operative times might relate more so to that than to the actual cannulation site. So that's another reason why we chose not to include those.

Dr Estrera. The last question is more of a minor question, but I thought it was interesting that the infection rates were different between the 2 groups. How would you explain that axillary versus central?

Dr Filtz. We've thought about that, too. We were unable to find exactly the site of the actual SSI for each of those cases. We were wondering if, for the axillary cannulation cases, it was in that incision rather than the medians sternotomy. We weren't able to find that and that's something that we would like to look more into in the future.

Dr Estrera. One last question. In 2022 at Columbia, you have a straightforward elective hemiarch, what are you going to cannulate?

Dr Filtz. The aorta would be our preference.

Dr Estrera. Very good. Keep it simple.

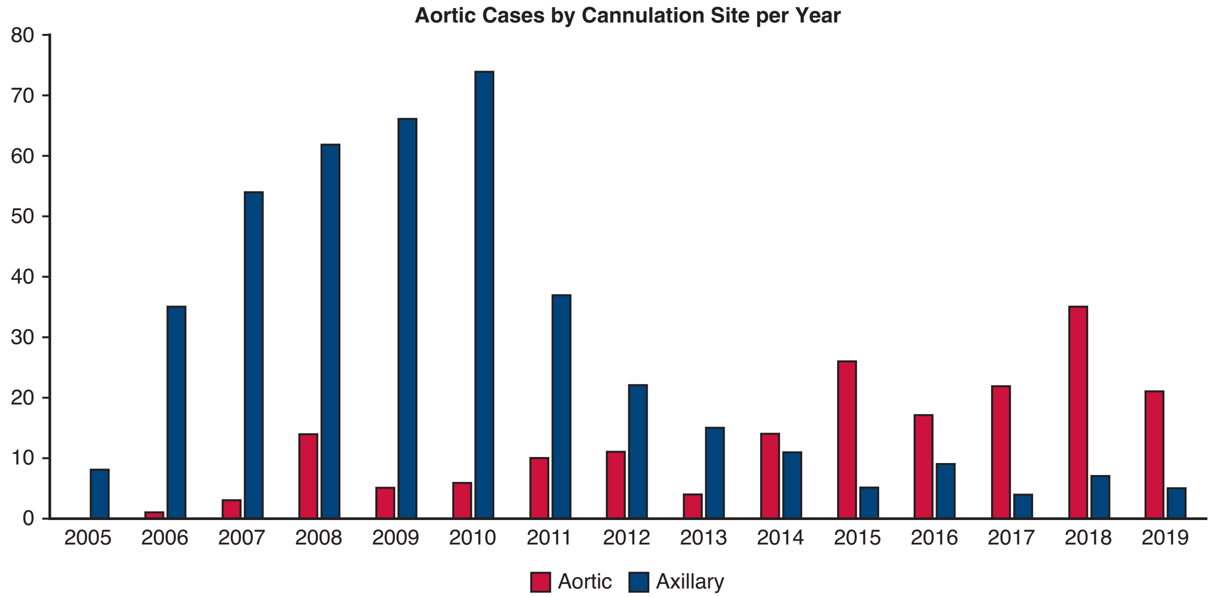


FIGURE E1. Trend of aortic and axillary cannulations over duration of study.

TABLE E1. Missing data

	N (%)	Management
Chronic obstructive pulmonary disease	4 Unknown (0.5)	Imputed to No
Urgent or emergency	1 Missing (0.1)	Imputed to Elective
Creatinine	2 Missing (0.3)	Imputed to Median
Body mass index	4 Missing (0.5)	Imputed to Median of Gender
Dyslipidemia	1 Unknown (0.1)	Imputed to No
Aortic insufficiency	5 Unknown (0.7) 1 Missing (0.1)	Imputed to No
Dialysis	2 Unknown (0.3)	Imputed to No
Concomitant aortic valve replacement	2 Missing (0.3)	Imputed to No
Cerebral vascular disease	1 Unknown (0.1)	Imputed to No
Cardiopulmonary bypass time	1 Missing (0.1)	Not used in matching
Aortic crossclamp time	1 Missing (0.1)	Not used in matching
ACP time	14 Missing (1.8)	Not used in matching

ACP, Antegrade cerebral perfusion.

TABLE E2. Multivariable logistic regression

	Odds ratio (95% CI)	*P* value
Age	1.02 (1.00-1.04)	.014
Diabetes	1.7 (0.91-3.16)	.094
Ejection fraction	0.99 (0.97-1.01)	.216
Peripheral vascular disease	1.28 (0.71-2.28)	.411
Cerebrovascular disease	1.01 (0.51-2.01)	.973
Aortic insufficiency	1.39 (0.89-2.19)	.149
Aortic stenosis	0.91 (0.52-1.60)	.75
Creatinine	5.05 (2.55-9.98)	.001
COPD	1.19 (0.74-1.92)	.465
CPB time	1.01 (1.01-1.01)	.001
Surgical indication	0.93 (0.71-1.21)	.576
Cannulation site	1.06 (0.67-1.67)	.819
Proximal extent of repair	4.29 (2.57-7.16)	.001
Distal extent of repair	1.09 (0.93-1.27)	.307

CI, Confidence interval; *COPD*, chronic obstructive pulmonary disease; *CPB*, cardiopulmonary bypass.