Is right axillary artery cannulation safe in type A aortic dissection with involvement of the innominate artery?

Bartosz Rylski, MD,^a Martin Czerny, MD,^a Friedhelm Beyersdorf, MD, PhD,^a Fabian Alexander Kari, MD,^a Matthias Siepe, MD,^a Hideo Adachi, MD, PhD,^b Atsushi Yamaguchi, MD, PhD,^b Ryo Itagaki, MD,^b and Naoyuki Kimura, MD, PhD^b

ABSTRACT

Objective: In patients with acute type A aortic dissection involving the innominate artery, it is unclear whether right axillary artery cannulation for arterial inflow is safe. We evaluated the surgical outcomes of patients with dissected innominate artery according to different arterial cannulation sites.

Methods: From 2005 to 2014, of 416 patients with acute type A aortic dissection and preoperative computed tomography angiography in 2 centers, 186 (aged 63 ± 13 years; 43% were female; 95% with DeBakey type I) had dissected innominate artery (84%, 9%, and 7% involving its entire length or more or less than half of its length, respectively). Neurologic complications, in-hospital mortality, and survival were compared between patients with right axillary (N = 84) and non-right axillary (N = 102) cannulation sites. Median follow-up was 30 months (range, 0-130 months).

Results: In-hospital mortality was 9.5% and 10.8% ($P = .97$) for patients with right and non-right axillary cannulation, respectively. Seven patients (8.3%) with right axillary cannulation and 9 patients (8.8%; $P = .89$) with non-right axillary cannulation had a new-onset postoperative stroke. The axillary artery was cannulated (although dissected) in 8 patients. None of them had a new-onset stroke or died perioperatively. The innominate artery remodeling was observed on follow-up computed tomography in 12% of right axillary cases and 14% of non-right axillary cases ($P = .82$). Survival did not differ between right axillary and non-right axillary cases, and measured $92\% \pm 3\%$ versus $87\% \pm 4\%$ and $85\% \pm 5\%$ versus $73\% \pm 9\%$ at 1 and 5 years, respectively (log rank, $P = .29$).

Conclusions: The right axillary artery is safe to cannulate for arterial inflow in patients with type A aortic dissection with dissected innominate artery. (J Thorac Cardiovasc Surg 2016;152:801-7)

Axillary artery cannulation in case of dissected innominate artery.

Central Message

The RAX artery is safe to cannulate for arterial inflow in patients with type A dissection with dissected innominate artery.

Perspective

This study evaluates the safety of RAX artery cannulation in case of a dissected innominate artery. We did not observe inferior outcomes in these patients when compared with other cannulation sites. These results may encourage cardiac surgeons to use the RAX artery for arterial inflow for the heart-lung machine regardless of innominate artery involvement in the dissection process.

See Editorial Commentary page 808.

Selecting the ideal arterial cannulation site for cardiopulmonary bypass (CPB) in patients with acute Stanford Type A dissection is critical. Currently advocated routes

include the axillary, common carotid, innominate, and femoral arteries, as well as the ascending aorta or apex of the left ventricle.¹

Axillary artery cannulation was first described by Villard and colleagues² in 1976 and reintroduced in the 1990s by Sabik and colleagues.³ Evidence is growing that axillary-artery cannulation is superior to other cannulation sites because it preserves antegrade flow in the descending aorta,

From the ^aDepartment of Cardiovascular Surgery, Heart Centre Freiburg University, Freiburg, Germany; and ^bDepartment of Cardiovascular Surgery, Jichi Medical University, Saitama Medical Centre, Saitama, Japan.

Read at the 29th European Association for Cardio-Thoracic Surgery Annual Meeting in Amsterdam, Netherlands, October 3-7, 2015. Winner of the Society of Thoracic Surgeons/European Association for Cardio-Thoracic Surgery 2015 Award.

Received for publication Feb 27, 2016; revisions received April 14, 2016; accepted for publication April 29, 2016; available ahead of print May 26, 2016.

Address for reprints: Bartosz Rylski, MD, Department of Cardiovascular Surgery, Heart Centre Freiburg University, Hugstetter Str. 55, 79106 Freiburg, Germany (E-mail: bartosz.rylski@universitaets-herzzentrum.de).

0022-5223/\$36.00

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<http://dx.doi.org/10.1016/j.jtcvs.2016.04.092>

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass
CT = computed tomography
RAX = right axillary

thereby reducing the risk for embolization and facilitating the administration of selective cerebral perfusion during aortic arch repair.⁴⁻⁶ These arguments led the authors of “2014 European Society of Cardiology Guidelines on the diagnosis and treatment of aortic diseases” to recommend that the axillary artery be considered the first choice for cannulation in surgery of the aortic arch and in type A dissection (class of recommendation I, level of evidence C).⁷

Axillary-artery cannulation in patients with a dissected innominate artery is controversial. Supra-aortic branches are involved in the dissection process in up to 37% of patients presenting with acute type A dissection.⁸ It is unclear whether right axillary (RAX) artery cannulation for arterial inflow in these patients is safe. It remains unknown what happens with both lumina of the dissected innominate artery during retrograde CPB blood flow after axillary-artery cannulation and whether there is a significant risk of false lumen expansion, true lumen collapse, and multiorgan malperfusion in this scenario. Our aim was to evaluate the efficacy and safety of RAX artery cannulation for aortic repair in patients with acute type A dissection with a dissected innominate artery.

MATERIALS AND METHODS

Patient Population

The institutional review committees at both participating centers approved this study, and the need for informed consent was waived. The Saitama Medical Centre in Saitama (Japan) and the Heart Centre Freiburg University in Freiburg and Bad Krozingen (Germany) reviewed their aortic databases covering patients undergoing operation since January 2008 in Saitama and from January 2005 in Freiburg to December 2014. Among 469 patients with acute type A aortic dissection, 416 had undergone high-quality preoperative computed tomography (CT) angiography. The study cohort comprises 186 patients (129 Saitama and 57 Freiburg patients; aged 63 ± 13 years; 43% were female; 95% with DeBakey type I) with dissected innominate artery (Figure 1). The process involved the entire length or more or less than half of the innominate artery length in 84%, 9%, and 7% of cases, respectively. Patients presenting a RAX cannulation site for arterial inflow for CPB (N = 84) were compared with patients who underwent non-RAX (N = 102) cannulation for arterial inflow. Neurologic complications, in-hospital mortality, and survival were compared.

Surgical Approach

All patients at both centers underwent emergency replacement of the entire ascending aorta. Proximal repair included resuspending the aortic valve, aortic valve replacement, aortic root replacement, or valve-sparing root replacement. Distal repair included isolated ascending, hemiarch, or total arch replacement depending on the entry tear location and aortic diameter, as described previously.⁹⁻¹² Aortic arch surgery was performed in hypothermic circulatory arrest with selective cerebral perfusion in all patients and with

FIGURE 1. Flow of patient selection process. CT, Computed tomography.

open distal anastomosis. In the early years of the study, hypothermic arrest was induced at 18°C. Currently, the temperature applied for hypothermic circulatory arrest ranges from 21°C to 25°C at both centers.

Arterial Cannulation Site

The ascending aorta, heart apex, supra-aortic, and femoral arteries were used for arterial inflow. In case of cardiogenic shock, femoral or apical (Saitama) cannulation was applied to promptly initiate CPB. In hemodynamically stable patients, femoral cannulation was preferred in the early study years, whereas axillary cannulation was favored later. The axillary artery was cannulated in all patients indirectly via a 10-mm (Saitama) or 8-mm (Freiburg) prosthesis anastomosed end-to-side to the axillary artery. Patients with non-RAX were cannulated at the right femoral artery (N = 36), heart apex (N = 28), left carotid artery (N = 10), left axillary artery (N = 9), left femoral artery (N = 5), ascending aortic (N = 3), and right carotid artery (N = 1). Two arterial cannulation sites were applied in 25 patients (30%) with RAX (N = 21 right femoral, N = 2 ascending aortic, N = 1 heart apex, N = 1 left femoral) and 9 patients (9%) with non-RAX (3 right femoral and heart apex; 2 right femoral and left axillary; 2 right femoral and ascending aortic; 1 right femoral and left carotid; 1 left femoral and left axillary). The second arterial cannulation site was chosen (1) to provide adequate body perfusion if there was a high line pressure during heart-lung machine initiation with single arterial in-flow cannula or the cooling process was slow (N = 2); (2) to achieve quicker cooling and rewarming if the patient was obese with a body mass index more than 30 kg/m² (N = 8); (3) to improve the lower body perfusion if the patient presented with lower-limb ischemia (N = 9); and (4) because of surgeon preferences (N = 15).

Patient Follow-up

Surveillance follow-up data were obtained for all patients by contacting the patients' general practitioners, the patients themselves, and their family members via aortic clinic office visits. Patients were followed up a total of 543 patient-years, with a median follow-up among survivors of 2.5 (first quartile, 0.6; third quartile, 4.2) years. CT for arterial remodeling analysis was obtained in 96% between 3 and 12 months after discharge.

Definitions

Shock is defined as a systolic blood pressure less than 80 mm Hg or any need for preoperative catecholamine therapy. Hemiarch is an open distal

TABLE 1. Demographics and clinical presentation

	All (n = 186)	RAX cannulation (n = 84)	Non-RAX cannulation (n = 102)	P value
Age (y)	63 (51; 71)	60 (51; 69)	67 (53; 74)	.033
>80 y	14 (7.5)	5 (6.0)	9 (8.8)	.646
Male gender	107 (57.5)	55 (65.5)	52 (51.0)	.066
Clinical presentation				
Hypertension	138 (74.2)	60 (71.4)	78 (76.5)	.539
Diabetes mellitus	10 (5.4)	5 (6.0)	5 (4.9)	.992
Current smoker	43 (23.1)	19 (22.6)	24 (23.5)	.978
COPD	10 (5.4)	6 (7.1)	4 (3.9)	.520
Coronary artery disease	7 (3.8)	3 (3.6)	4 (3.9)	.793
Prior stroke	13 (7.0)	4 (4.8)	9 (8.8)	.428
Prior TND	3 (1.6)	2 (2.4)	1 (1.0)	.865
Previous cardiac surgery	0	0	0	
MFS	10 (5.4)	4 (4.8)	6 (5.9)	.992
Bicuspid aortic valve	4 (2.2)	1 (1.2)	3 (2.9)	.756
DeBakey I	176 (94.6)	79 (94.0)	97 (95.1)	.992
Cardiogenic shock	32 (17.2)	5 (6.0)	27 (26.5)	<.001
Cardiac tamponade	25 (13.4)	4 (4.8)	21 (20.6)	.003
Malperfusion				
At least 1 organ	80 (43.0)	29 (34.5)	51 (50.0)	.038
Coronary	18 (9.7)	8 (9.5)	10 (9.8)	.835
Cerebral	39 (21.0)	13 (15.5)	26 (25.5)	.137
Iliofemoral	30 (16.1)	10 (11.9)	20 (19.6)	.222
Gastrointestinal	17 (9.1)	6 (7.1)	11 (10.8)	.547
Renal	14 (7.5)	5 (6.0)	9 (8.8)	.646
Spinal	2 (1.1)	1 (1.2)	1 (1.0)	.565

Categoric values are n (%), and continuous values are median (first quartile; third quartile). RAX, Right axillary; COPD, chronic obstructive pulmonary disease; TND, temporary neurologic dysfunction; MFS, Marfan syndrome.

anastomosis with an excision of lesser curvature. Total arch is defined as reimplantation of 1 or more supra-aortic vessels. Respiratory failure is defined as mechanical ventilation more than 48 hours. Arterial remodeling is defined as a lack of dissection or intramural hematoma in the artery, which was dissected or had intramural hematoma at the initial CT angiography with an acute type A aortic dissection.

Statistical Analysis

Continuous data are presented as median (first quartile, third quartile); categoric variables are given as counts and percentages. To compare continuous variables, the Mann–Whitney rank-sum test was used. Categoric variables were compared using the Fisher exact test. Survival was analyzed via the Kaplan–Meier method and log-rank calculations.

Propensity score matching was used to adjust for baseline characteristics. Because of the relatively low number of patients, only the most clinically important variables were entered in the propensity score matching analysis. Selected variables were age, male gender, Marfan syndrome, cardiogenic shock, tamponade, at least 1 organ ischemia, aortic root replacement, and aortic arch replacement. On the basis of propensity scores, 69 pairs were successfully matched in a 1-to-1 manner. All statistical calculations were performed using SigmaPlot, version 12 (Systat Software, San Jose, Calif) and IBM SPSS Statistics, version 23.0 (IBM Corp, Armonk, NY).

RESULTS

Demographics and Clinical Presentation

Patient demographics are summarized in Table 1. Patients with RAX were significantly younger than patients with non-RAX (60 [51-69] years vs 67 [53-74] years;

$P = .03$); however, the number of octogenarians was similar in both groups ($P = .65$). We noted a trend toward more male patients in the RAX cannulation group ($P = .07$). Patients with RAX and non-RAX presented similar cardiovascular risk profiles. The number of patients with cardiogenic shock was significantly lower in the RAX group (6% vs 27%, $P < .001$). We observed a higher incidence of malperfusion syndrome of at least 1 organ in the non-RAX group (RAX 34.5% vs non-RAX 50.0%, $P = .14$).

Dissection Anatomy

A total of 94% of patients had DeBakey type I in the RAX group, and 95% of patients had DeBakey type I in the non-RAX group. The entire length of the innominate artery was dissected in more than two thirds of all patients. The RAX artery was less frequently dissected in the RAX group (10% vs 23%, $P = .03$). The dissection extension to peripheral arteries is presented in Table 2.

Surgical Management, Perioperative Outcome, and Survival

Supracoronary ascending replacement and isolated ascending replacement without aortic arch repair were performed in the majority of RAX and non-RAX cases

TABLE 2. Dissection extension into supra-aortic and iliac arteries at initial computed tomography

	All (n = 186)	RAX cannulation (n = 84)	Non-RAX cannulation (n = 102)	P value
Innominate artery				
Entire length	137 (73.7)	58 (69.0)	79 (77.5)	.378
More than half length	16 (8.6)	9 (10.7)	7 (6.9)	.268
Less than half length	33 (17.7)	17 (20.2)	16 (15.7)	.538
RAX	31 (16.7)	8 (9.5)	23 (22.5)	.030
Right carotid	110 (59.1)	45 (53.6)	65 (63.7)	.211
Left carotid	77 (41.4)	33 (39.3)	44 (43.1)	.703
Left axillary	68 (36.6)	30 (35.7)	38 (37.3)	.949
Right iliac	80 (43.0)	39 (46.4)	41 (40.2)	.156
Left iliac	86 (46.2)	40 (47.6)	46 (45.1)	.386

RAX, Right axillary.

(80% vs 86%, $P = .31$ and 63% vs 64%, $P = .95$, respectively) (Table 3). CPB, aortic crossclamping, and hypothermic circulatory arrest times were similar in both groups. The RAX group underwent selective cerebral perfusion more frequently (57% vs 30%, $P < .001$).

There were no group differences with regard to re-thoracotomy for bleeding ($P = .88$), renal failure ($P = .99$), respiratory failure ($P = .57$), and postoperative new-onset stroke ($P = .85$). In-hospital mortality was 9.5% in the RAX group and 10.8% in the non-RAX group ($P = .97$).

Survival did not differ between RAX and non-RAX groups, measuring $92\% \pm 3\%$ versus $87\% \pm 4\%$ and

$85\% \pm 5\%$ versus $73\% \pm 9\%$ at 1 and 5 years, respectively (log rank, $P = .29$) (Figure 2, A).

Remodeling of Primarily Dissected Arteries

No more dissections were detectable in the innominate artery at CT angiography follow-up in 12% of the RAX group and 14% of the non-RAX group ($P = .82$). Remodeling of the RAX artery was observed in 13% of the RAX group and 17% of the non-RAX group ($P = 1$) with a primarily dissected RAX artery. The highest degree of remodeling was observed in the primarily dissected right carotid artery in the non-RAX group (26%) (Figure E1). There was no significant difference between the RAX and

TABLE 3. Surgery for type A aortic dissection details and outcomes

	All (n = 186)	RAX cannulation (n = 84)	Non-RAX cannulation (n = 102)	P value
Proximal repair				
Supracoronary ascending replacement	155 (83.3)	67 (79.8)	88 (86.3)	.310
Aortic root replacement	30 (16.1)	16 (19.0)	14 (13.7)	.434
David operation	1 (0.5)	1 (1.2)	0	.922
Distal repair				
Isolated ascending replacement	118 (63.4)	53 (63.1)	65 (63.7)	.949
Hemiarch replacement	38 (20.4)	16 (19.0)	22 (21.6)	.809
Total arch replacement	30 (16.1)	15 (17.9)	15 (14.7)	.703
Antegrade TEVAR	2 (1.1)	1 (1.2)	1 (1.0)	.565
CPB time (min)	166 (123; 217)	178 (125; 237)	156 (121; 203)	.075
CX time (min)	102 (82; 137)	107 (84; 146)	98 (81; 133)	.299
HCA time (min)	29 (19; 37)	27 (0; 38)	29 (24; 37)	.121
Antegrade cerebral perfusion	79 (42.5)	48 (57.1)	31 (30.4)	<.001
Deep hypothermic circulatory arrest	107 (57.5)	36 (42.9)	71 (69.6)	<.001
Lowest body temperature (°C)	20.0 (18.6; 22.4)	20.6 (18.9; 23.3)	19.9 (18.6; 21.2)	.184
Reexploration for bleeding	15 (8.1)	6 (7.1)	9 (8.8)	.882
Stroke, new onset	18 (9.7)	8 (9.5)	10 (9.8)	.853
TND	16 (8.6)	9 (10.7)	7 (6.9)	.503
Renal failure	17 (9.1)	6 (7.1)	11 (10.8)	.991
Respiratory failure	86 (46.2)	41 (48.8)	45 (44.1)	.570
ICU time	6 (4; 10)	6 (3; 10)	6 (4; 10)	.866
In-hospital time	20 (14; 28)	21 (14; 29)	20 (14; 28)	.739
In-hospital mortality	19 (10.2)	8 (9.5)	11 (10.8)	.969

Categoric values are n (%), and continuous values are median (first quartile; third quartile). RAX, Right axillary; TEVAR, thoracic endovascular aortic repair; CPB, cardiopulmonary bypass; CX, crossclamp; HCA, hypothermic circulatory arrest; TND, temporary neurologic dysfunction; ICU, intensive care unit.

FIGURE 2. Survival after surgery for acute type A aortic dissection in (A) all and (B) propensity score–matched patients with dissected innominate artery. RAX, Right axillary.

non-RAX groups in the frequency of remodeling in primarily dissected arteries.

Cannulation of Dissected Right Axillary Artery

The RAX artery was cannulated in 8 patients with RAX, although it was dissected. Of those, 4 presented a concomitant right carotid artery dissection. The axillary artery was cannulated in all via a Dacron graft anastomosed end-to-side to the true lumen. None of those patients had a new-onset postoperative stroke or perioperative death. Reversible postoperative renal failure developed in 1 patient, and a transient ischemic attack developed in 1 patient. We observed a remodeled RAX artery at follow-up in 1 patient.

Outcome in Matched Cohorts

The standardized mean difference of all covariates included in the propensity score–matched analysis, with the exception of “at least 1 organ malperfusion” (standardized mean difference = 0.17), was less than 0.1, indicating that a good balance and successful bias reduction were achieved in both groups (Table 4). There were no group differences with regard to re-thoracotomy for bleeding (6% vs 10%, $P = .53$), renal failure (12% vs 13%, $P = .82$), respiratory failure (49% vs 44%, $P = .44$), and postoperative new-onset stroke (12% vs 10%, $P = .78$). In-hospital mortality was 11.6% in the matched RAX cases and 7.2% in the matched non-RAX cases ($P = .56$) (Table 4). Survival did not differ between matched RAX and non-RAX cases (log rank, $P = .882$) (Figure 2, B).

DISCUSSION

This study addresses whether RAX artery cannulation in type A aortic dissection with dissected innominate artery is

safe. The RAX artery is one of the most popular cannulation sites in patients presenting with type A dissection.¹ Previous reports have suggested the superiority of axillary cannulation versus femoral cannulation due to a decreased stroke risk,^{13,14} lower in-hospital mortality,^{5,6} and better long-term survival.¹⁵ However, there are no data revealing whether innominate artery dissection should be a contraindication for RAX artery cannulation.

Despite many improvements in treating acute type A aortic dissection, in-hospital mortality after surgery remains high, usually between 17% reported in the German Registry for Acute Aortic Dissection Type A⁸ and 24% among patients in the International Registry of Acute Aortic Dissection,¹⁶ decreasing to 10% to 15% in most experienced hands.^{10-12,17,18} Perioperative mortality is strongly associated with malperfusion and varies depending on the number of organ systems affected (up to 43% in patients with 3-organ malperfusion syndrome).¹⁹ The impaired flow in the brain-supplying arteries is one of the most frequent manifestations of malperfusion²⁰ and may lead to serious irreversible neurologic complications. The surgeon’s cannulation strategy is a critical factor that defines organ perfusion during surgery and therefore may play a crucial role in the operative outcome.²¹

One could argue that innominate artery involvement in the dissection process is a contraindication for RAX cannulation because of the potential risk of false lumen expansion and true lumen collapse leading to multiorgan malperfusion, which is usually fatal. Our results show that the innominate artery is frequently (45%) dissected in patients with type A aortic dissection. However, we observed no differences in short- and midterm outcomes in patients who did or did not undergo axillary cannulation in case of a dissected innominate artery. Moreover, we

TABLE 4. Propensity score–matched patients characteristic and outcome

Characteristic	RAX cannulation (n = 69)	Non-RAX cannulation (n = 69)	P value	SMD
Age (y)	61 (51; 69)	63 (53; 71)	.443	0.013
Male gender	40 (58.0)	38 (55.1)	.730	−0.058
MFS	4 (5.8)	5 (7.2)	1.000	0.058
Cardiogenic shock	5 (7.2)	4 (5.8)	1.000	−0.058
Cardiac tamponade	4 (5.8)	3 (4.3)	1.000	−0.065
At least 1 organ malperfusion	26 (37.7)	32 (46.4)	.301	0.170
Aortic root replacement	8 (11.6)	9 (13.0)	.793	0.043
Aortic arch replacement	15 (21.7)	10 (14.5)	.272	−0.180
Outcome				
Reexploration for bleeding	4 (5.8)	7 (10.1)	.530	
Stroke, new onset	8 (11.6)	7 (10.1)	1.000	
TND	8 (11.6)	5 (7.2)	.560	
Renal failure	8 (11.6)	9 (13.0)	.589	
Respiratory failure	34 (49.3)	30 (43.5)	.451	
ICU time	9 (3; 10)	9 (4; 10)	.635	
In-hospital time	27 (14; 30)	29 (17; 30)	.806	
In-hospital mortality	8 (11.6)	5 (7.2)	.560	

Categoric values are n (%), and continuous values are median (first quartile; third quartile). RAX, Right axillary; SMD, standardized mean difference; MFS, Marfan syndrome; TND, temporary neurologic dysfunction; ICU, Intensive care unit.

observed no postoperative adverse events associated with axillary artery cannulation in patients with a dissected axillary artery. However, in case of entry located in the innominate artery, CPB inflow via the RAX artery may pressurize the false lumen and therefore lead to false lumen expansion and true lumen collapse (Figure 3). This is usually noticed shortly after CPB initiation because of low CPB flow caused by high arterial resistance or a decrease in near-infrared spectroscopy. It is not possible to definitively exclude dissection entries in peripheral arteries such as the innominate artery in CT. However, whenever there is high arterial resistance at the beginning of CPB circulation, or the near-infrared spectroscopy decreases, and the patient is cannulated via the RAX artery in the presence of dissection involving the innominate artery, the previously mentioned pathogenic mechanisms must be considered and a secondary arterial cannulation site should be performed immediately. We observed this complication in 1 patient with aortic rupture similar to cases described in the literature.^{22,23} Moreover, 25 patients with RAX were cannulated for different reasons, including surgeon’s preference, patients’ obesity, and limb ischemia prevention, at 2 different sites simultaneously, which might have prevented true lumen collapse if there was an entry in the innominate artery (Figure 3). Because of the retrospective study design, it is not possible to give a definitive number of patients whose second cannulation was unavoidable to provide adequate CPB flow.

FIGURE 3. Hypothetical pathomechanism of false lumen expansion and true lumen collapse after cannulation of the axillary artery in case of entry tear in the innominate artery. CPB inflow through the RAX artery may pressurize via the entry tear the false lumen and lead to true lumen collapse, which is usually noticed by high arterial resistance and low CPB flow. CPB, Cardiopulmonary bypass; RCC, right common carotid; LCC, left common carotid; LAX, left axillary; RAX, right axillary.

The literature on remodeling the peripheral arteries after surgery for type A dissection is limited to coronary arteries remodeling after iatrogenic dissection due to catheter manipulations.^{24,25} In our study, we analyzed follow-up changes in dissection extending into arteries coming off the aorta. We observed no significant difference in the remodeling frequency in primarily dissected peripheral arteries in conjunction with the cannulation site. The highest remodeling rate (26%) was observed in the primarily dissected right carotid artery in the non-RAX group. However, this was not significantly different from the remodeling observed in RAX group.

CONCLUSIONS

Our findings support using the axillary artery for arterial inflow for the heart-lung machine regardless of innominate artery involvement in the dissection process.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: aortic dissection, cerebral ischemia, stroke

FIGURE E1. Remodeling of primarily dissected arteries. There is no significant difference in remodeling incidence in primarily dissected arteries between RAX and non-RAX cases. Arterial remodeling is defined as a lack of dissection or intramural hematoma in the artery, which was dissected or had intramural hematoma at the initial CT angiography with an acute type A aortic dissection. *RAX*, Right axillary; *INN*, innominate artery; *RCC*, right common carotid; *LCC*, left common carotid; *LAX*, left axillary; *RIL*, right iliac; *LIL*, left iliac.