

Aortic and innominate cannulations are equally safe in redo aortic surgery



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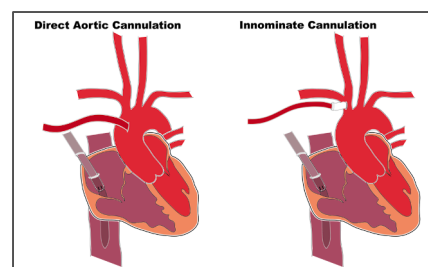
ABSTRACT

Objective: Chest reentry poses challenges for establishing cardiopulmonary bypass. This study aimed to compare postoperative neurologic outcomes between aortic (AC) and innominate cannulation (IC) in redo aortic surgery.

Methods: We retrospectively reviewed 201 patients undergoing redo sternotomy for aortic aneurysm repair from 2010 to 2024. Patients were stratified by cannulation site: AC (n = 119) or IC (n = 34); 48 patients who underwent other approaches were excluded. Demographics, intraoperative variables, and postoperative outcomes were compared. Propensity-score matching (PSM), logistic regression, and Kaplan-Meier analyses were performed.

Results: Median age was 62.4 years; 75.8% were male. Before PSM, patients in the AC group had a lower smoking rate (38.7% vs 64.7%, $P = .012$) but a greater incidence of partial/total arch replacement (68.9% vs 23.5%, $P < .001$) compared with those in IC. IC was associated with lower nadir temperature (26.9 vs 27.5 °C, $P = .044$), longer crossclamp time (108.5 vs 87 minutes, $P < .001$), and more antegrade cerebral perfusion alone (91.2% vs 29.4%, $P < .001$). IC required more intraoperative fresh-frozen plasma (6 vs 4 units, $P = .001$). After PSM, crossclamp time did not differ, but IC had longer circulatory arrest (13 vs 9.4 minutes, $P = .004$) and lower end left cerebral oxygen saturation (67% vs 70%, $P = .021$). Postoperative stroke, encephalopathy/delirium, and mortality were similar. In multivariable regression analysis, cannulation site was not associated with postoperative stroke. Ten-year survival rates were 66.6% for AC and 65.0% for IC ($P_{\log\text{-rank}} = .551$).

Conclusions: AC and IC are safe in redo sternotomy for aortic surgery, with similar neurologic and survival outcomes reported. Surgeons may choose either approach on the basis of preference and patient anatomy. (JTCVS Open 2026;33:102086)



Aortic and innominate cannulations are feasible and safe options in redo aortic surgery.

CENTRAL MESSAGE

In redo aortic surgery, aortic and innominate cannulations are both safe with similar rates of neurologic complications, in-hospital mortality, and long-term survival.

PERSPECTIVE

Although redo sternotomy introduces significant challenges, the choice of an arterial inflow site for cardiopulmonary bypass is important due to its neurologic implications. This study shows similar postoperative stroke and mortality outcomes with aortic versus innominate cannulation, supporting the safety of both approaches. Surgeons may therefore use either strategy according to operative preference.

In redo aortic surgery, dense mediastinal adhesions complicate reentry into the thoracic cavity and cannulation for cardiopulmonary bypass (CPB), and reoperation has been

associated with increased perioperative complications, morbidity, and mortality.¹⁻⁵ In this setting, selecting an arterial inflow site for CPB is a critical decision, with neurologic and hemodynamic implications.

Contemporary guidelines favor antegrade CPB arterial inflow over retrograde femoral cannulation, because the latter has been linked to embolic stroke and greater early mortality.⁶⁻¹¹ Antegrade perfusion options include direct cannulation of the ascending aorta or arch, as well as cannulation of the supra-aortic vessels. Direct aortic and right axillary or subclavian cannulations are recommended for primary aortic hemiarch and arch operations, with similar reported outcomes.^{8,10-14}

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Read at the 63rd Annual Meeting of the Eastern Cardiothoracic Surgical Society, Amelia Island, Florida, October 15-18, 2025.

Received for publication April 9, 2026; revisions received Aug 7, 2026; accepted for publication Aug 13, 2026; available ahead of print Aug 27, 2026.

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2666-2736

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<https://doi.org/10.1016/j.xjon.2026.102086>

Abbreviations and Acronyms

AC	= aortic cannulation
ACP	= antegrade cerebral perfusion
aOR	= adjusted odds ratio
CPB	= cardiopulmonary bypass
IC	= innominate artery cannulation
PSM	= propensity-score matching
RCP	= retrograde cerebral perfusion
SACP	= selective antegrade cerebral perfusion
TAAD	= type A aortic dissection
XC	= crossclamp

In the setting of redo sternotomy, however, the choice between central antegrade cannulation strategies for CPB, specifically direct aortic cannulation (AC) versus innominate artery cannulation (IC), remains less clearly defined. Although direct AC has gained increasing popularity,^{12,14} concerns persist regarding safety during redo mediastinal exposure and aortic manipulation. By contrast, IC offers an alternative central antegrade inflow site that may facilitate cerebral perfusion and reduce direct manipulation of the ascending aorta, but it has been more commonly studied in the context of selective antegrade cerebral perfusion (SACP) rather than as the primary arterial inflow for CPB initiation.¹⁵⁻¹⁹ Accordingly, we sought to evaluate the impact of these 2 central antegrade cannulation strategies on postoperative complications and long-term survival in patients undergoing redo aortic surgery.

METHODS**Study Design and Cohort**

We conducted a retrospective cohort study in which we examined the results of a single-center aortic surgery database from April 2010 to December 2024. A total of 201 patients who underwent reoperative sternotomy for ascending and/or aortic arch aneurysm repair were identified. Operative indications included degenerative aneurysmal disease and aneurysmal degeneration of residual chronic dissection in patients with a history of type A aortic dissection. For the present study, only patients who received either direct AC (n = 119) or IC (n = 34) for CPB arterial inflow were included. Patients who underwent axillary (n = 39) or other cannulation approaches (n = 9) were excluded. The study design was approved by the Colorado Multiple Institutional Review Board (COMIRB #19-0484, approval date March 5, 2019), with written consent waived for retrospective analysis.

Operative Technique

Reoperative sternotomy. A midline chest incision was made. Soft tissues were sharply dissected to the level of sternum, and the retrosternal space was carefully

developed. Previous sternal wires were exposed and divided. After confirmation of adequate blood availability in the event of unexpected vascular injury, the anterior sternal table was divided using an oscillating saw, followed by division of the posterior table with serrated scissors. Hemostasis was achieved with electrocautery along the anterior and posterior tables and Gelfoam application to the bone marrow surfaces. The sternum was then retracted to expose the mediastinum.

Direct aortic cannulation. After mediastinal exposure, the ascending aorta and aortic arch were carefully dissected and exposed. A soft-flow arterial cannula was inserted into the distal ascending aorta, proximal aortic arch, or previous aortic graft. The cannula was then secured and connected to the CPB arterial line (Figure 1, left). The remainder of CPB setup was completed, and systemic cooling was initiated according to institutional protocol and surgeon preference.

Innominate artery cannulation. After mediastinal exposure, the innominate artery was carefully dissected to obtain proximal and distal control. Once adequate activated clotting time was achieved via systemic heparinization, an arteriotomy was created, and a 10-mm Dacron graft was sewn in an end-to-side fashion (Figure 1, right). Side-graft cannulation avoids narrowing the native innominate lumen with a cannula and enables more controlled arterial inflow. After graft deairing and connection to the arterial inflow line, the pericardium was opened to proceed with the subsequent steps of aortic repair. Early in our experience, direct cannulation without a conduit could be performed and was used in 2 patients.

Statistical Methods and Analysis

All statistical analysis was carried out using R (version 4.5.0) with open-sourced libraries. Data normality was assessed using the Shapiro-Wilk test. Continuous variables were compared using the Student *t* test or the Mann-Whitney *U* test, as appropriate. Categorical variables were compared using the χ^2 test or Fisher exact test. These analyses were used to compare demographic characteristics, preoperative comorbidities, operative details, CPB and cerebral perfusion parameters, and postoperative outcomes. Propensity-score matching (PSM) at a 1:1 ratio was performed as a sensitivity analysis by adjusting for age, sex, body mass index, smoking history, and comorbidities including hypertension, diabetes mellitus, history of cerebrovascular accident, atrial fibrillation, pulmonary disease, preoperative dialysis, urgency status, and extent of aortic arch replacement. Univariable and multivariable logistic regression analyses were conducted to identify factors associated with postoperative stroke (in-hospital or within 30 days). Survival status was collected from electronic medical records. Patients without documented death were censored at the date of last known alive. Kaplan-Meier survival analysis was used to assess 10-year survival outcomes.

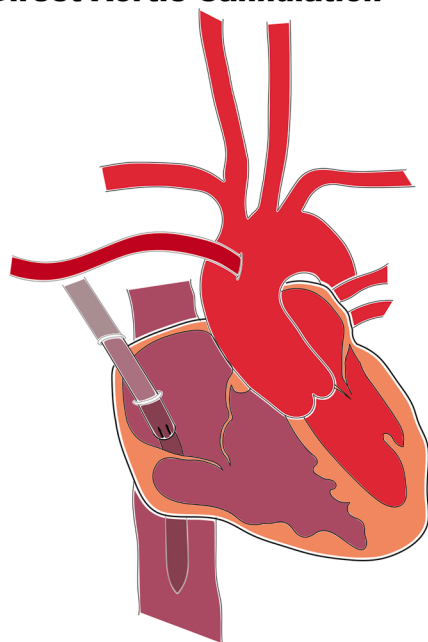
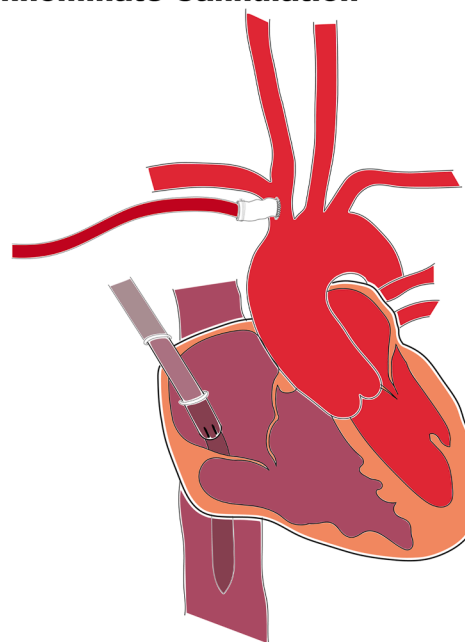
Direct Aortic Cannulation**Innominate Cannulation**

FIGURE 1. Illustration of direct aortic cannulation (*left*) and innominate cannulation (*right*).

Survival curves between groups were compared using the log-rank test. Data are presented as median [interquartile range] for continuous variables and number (percentage) for categorical variables.

RESULTS

Baseline Characteristics

Among the 153 patients included, 119 (77.8%) underwent AC and 34 (22.2%) underwent IC for CPB. 103 (86.6%) AC cases and 5 (14.7%) IC cases were performed in 2019 or later. In the unmatched cohort, age (median 62.4 [51.6-69.8] vs 60.5 [50.7-68.6] years), sex (male 72.3% vs 88.2%), and body mass index (28.2 [24.4-32] vs 27.6 [24.8-31.5]) were similar between the 2 groups. No significant differences were observed in rates of preoperative comorbidities, including hypertension, diabetes, and previous stroke. However, patients undergoing IC had a greater history of smoking (64.7% vs 38.7%; $P = .012$). Previous surgical history was heterogeneous. Overall, 143 patients (93.5%) underwent true redo aortic surgery, defined as having history of previous aortic surgery involving the aortic root, ascending aorta, or aortic arch. A total of 33 patients (21.6%) had undergone previous isolated aortic valve intervention. After PSM, all baseline variables were well-balanced with no significant differences (Table 1).

Aortic Repair and Operative Times

In the unmatched cohort, the extent of arch replacement was significantly different. IC was predominantly used in hemiarch procedures (76.5% vs 31.1%, $P < .001$), whereas

AC was more common for partial/total arch replacement (68.9% vs 23.5%, $P < .001$). In the matched cohort, this difference was no longer observed (hemiarch: 76.5% vs 73.5%, $P = 1.000$). Two reentry injuries occurred in the AC group, whereas none occurred in the IC group ($P = 1.000$) (Table 2).

Before matching, IC was associated with longer cross-clamp (XC) time (108.5 [78.8-141.5] vs 87 [52-111] minutes; $P = .011$). After matching, CPB and XC times were similar ($P > .40$). However, IC was associated with longer hypothermic circulatory arrest (13 [10-21.5] vs 8.5 [6.3-16.8] minutes, $P = .004$). In addition, the IC group had a lower nadir temperature (26.9 °C [25.6-27.8 °C] vs 27.9 °C [27.1-28.4 °C], $P = .002$). Cooling and rewarming times did not differ between groups.

Cerebral Protection and Perfusion Strategies

Cerebral perfusion strategies varied markedly by cannulation site ($P < .001$) (Table 2). IC was almost uniformly used with antegrade cerebral perfusion (ACP) alone (91.2%), whereas AC included a mix of strategies, with ACP only (29.4%), retrograde cerebral perfusion (RCP) only (31.9%), or both (37.8%). When ACP was used, bilateral ACP was less common with IC (5.9% vs 53.8%, $P < .001$), and dual perfusion, defined as simultaneous cerebral and systemic lower-body perfusion, after distal anastomosis was also less frequent with IC (17.6% vs 53.8%, $P < .001$). Regional cerebral oxygen saturation at multiple time points was similar in the unmatched analysis. In the matched analysis; however, the left-sided end regional

TABLE 1. Baseline characteristics in patients undergoing redo aortic surgery

Demographics	Unmatched				Matched			
	Aortic (n = 119)	Innominate (n = 34)	Overall (N = 153)	P value	Aortic (n = 34)	Innominate (n = 34)	Overall (N = 68)	P value
Age, y	62.4 [51.6-69.8]	60.5 [50.7-68.6]	62.4 [51.1-69.8]	.767	62 [46.8-72.5]	60.5 [50.7-68.6]	61.5 [49.6-70.4]	.978
Gender (male)	86 (72.3%)	30 (88.2%)	116 (75.8%)	.091	31 (91.2%)	30 (88.2%)	61 (89.7%)	1.000
BMI	28.2 [24.4-32]	27.6 [24.8-31.5]	28 [24.6-31.9]	.918	27.4 [23.9-30.5]	27.6 [24.8-31.5]	27.6 [24.3-31.2]	.784
Smoking	46 (38.7%)	22 (64.7%)	68 (44.4%)	.012	21 (61.8%)	22 (64.7%)	43 (63.2%)	1.000
HTN	103 (86.6%)	25 (73.5%)	128 (83.7%)	.121	27 (79.4%)	25 (73.5%)	52 (76.5%)	.775
Diabetes	10 (8.4%)	3 (8.8%)	13 (8.5%)	1.000	2 (5.9%)	3 (8.8%)	5 (7.4%)	1.000
Hx of stroke	18 (15.1%)	8 (23.5%)	26 (17%)	.373	6 (17.6%)	8 (23.5%)	14 (20.6%)	.764
Hx of TIA	8 (6.7%)	2 (5.9%)	10 (6.5%)	1.000	2 (5.9%)	2 (5.9%)	4 (5.9%)	1.000
Afib	23 (19.3%)	5 (14.7%)	28 (18.3%)	.716	5 (14.7%)	5 (14.7%)	10 (14.7%)	1.000
Pulmonary disease	42 (35.3%)	10 (29.4%)	52 (34%)	.665	8 (23.5%)	10 (29.4%)	18 (26.5%)	.783
Dialysis	1 (0.8%)	1 (2.9%)	2 (1.3%)	.396	0 (0.0%)	1 (2.9%)	1 (1.5%)	1.000
Urgent/emergent	18 (15.1%)	10 (29.4%)	28 (18.3%)	.099	9 (26.5%)	10 (29.4%)	19 (27.9%)	1.000

Data are presented as median interquartile range or n (%). *P* values compare aortic cannulation (AC) with innominate cannulation (IC). Propensity matching was performed for age, sex, body mass index, smoking history, hypertension, diabetes mellitus, history of stroke, history of transient ischemic attack, atrial fibrillation, pulmonary disease, preoperative dialysis, urgency status, and extent of arch intervention. *BMI*, Body mass index; *HTN*, hypertension; *Hx*, history; *TIA*, transient ischemic attack; *Afib*, atrial fibrillation.

cerebral oxygen saturation was lower in the IC group (67% [59.5%-72%] vs 70% [66%-75%]; *P* = .021), along with a negative deviation from baseline (−4.8% [−9.8 to 0.3] vs 1.4% [−4.8 to 7.7], *P* = .015).

Intraoperative Transfusions

In the unmatched cohort, the IC group required more units of fresh-frozen plasma (6 [4-8] vs 4 [1-6] units, *P* = .001). Requirements for packed red blood cells, platelets, and cryoprecipitate were similar between the groups. Similarly, after matching, IC required more fresh-frozen plasma (6 [4-8] vs 3.5 [2-5], *P* = .009), but transfusion requirements for other products were similar (Table 3).

Postoperative Outcomes

Before and after matching, rates of encephalopathy/delirium, stroke, atrial fibrillation, acute kidney injury, new renal failure requiring dialysis, and in-hospital mortality did not differ significantly between AC and IC (Table 4).

Predictors of Postoperative Stroke

Both univariable and multivariable logistic regression results are shown in Table 5. In multivariable analysis, partial/total arch replacement (adjusted odds ratio [aOR], 3.21; 95% CI, 0.996-10.360, *P* = .051) and urgent/emergent presentation (aOR, 2.839; 95% CI, 0.967-8.331, *P* = .057) each showed a borderline greater risk of stroke, whereas

cannulation site (IC vs AC) was not associated with stroke (aOR, 1.49; 95% CI, 0.427-5.262; *P* = .528).

Follow-Up Status

Lost to follow-up with cardiac surgery within 1 year was common and more frequent with IC in the unmatched cohort (70.6% vs 44.5%; *P* = .013), whereas the lost to follow-up rates with any cardiovascular provider were similar (38.2% vs 32.8%, *P* = .698).

Long-Term Survival Outcome

Kaplan-Meier analysis of long-term survival (Figure 2) demonstrated no significant difference between the cannulation strategies (log-rank *P* = .551). Estimated survival at 3, 5, and 10 years was 85.2%, 77.7%, and 66.6% for AC and 83.9%, 70.0%, and 65.0% for IC, respectively.

DISCUSSION

Redo sternotomy adds substantial complexity to aortic arch surgery, underscoring the need for operative strategies that streamline the operation while improving outcomes. Although multiple cannulation sites can be chosen to establish CPB, patient anatomy and arterial pathology may preclude the use of certain approaches. Preoperative computed tomography is useful for assessing atherosclerosis, dissection, and retrosternal structures to determine vessel suitability for cannulation and clamping. In our practice, we have transitioned from axillary to innominate

TABLE 2. Intraoperative and perfusion data

Variable	Unmatched				Matched			
	Aortic (n = 119)	Innominate (n = 34)	Overall (n = 153)	P value	Aortic (n = 34)	Innominate (n = 34)	Overall (n = 68)	P value
Intraoperative								
Aortic procedure type								
Hemiarch	37 (31.1%)	26 (76.5%)	63 (41.2%)	<.001	25 (73.5%)	26 (76.5%)	51 (75%)	1.000
Partial/total arch	82 (68.9%)	8 (23.5%)	90 (58.8%)	<.001	9 (26.5%)	8 (23.5%)	17 (25%)	1.000
Concomitant CABG	13 (10.9%)	2 (5.9%)	15 (9.8%)	.524	7 (20.6%)	2 (5.9%)	9 (13.2%)	.150
True redo	114 (95.8%)	29 (85.3%)	143 (93.5%)	.044	31 (91.2%)	29 (85.3%)	60 (88.2%)	.709
Previous isolated aortic valve intervention	20 (16.8%)	13 (38.2%)	33 (21.6%)	.015	12 (35.3%)	13 (38.2%)	25 (36.8%)	1.000
Reentry injury	2 (1.7%)	0 (0.0%)	2 (1.3%)	1.000	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.000
CPB/XC/HCA details								
Nadir bladder temperature	27.5 [26.1-28]	26.9 [25.6-27.8]	27.4 [26-28]	.044	27.9 [27.1-28.4]	26.9 [25.6-27.8]	27.6 [26-28]	.002
CPB time	158 [132-205.5]	167.5 [133.8-200.8]	161 [132-204]	.845	148 [119.2-198.2]	167.5 [133.8-200.8]	160 [125.5-201.2]	.477
XC time	87 [52-111]	108.5 [78.8-141.5]	92 [60-121.2]	.011	96 [80-151.8]	108.5 [78.8-141.5]	107 [78.8-143.2]	.849
HCA time	15 [9-20.4]	13 [10-21.5]	15 [9-20.4]	.885	8.5 [6.3-16.8]	13 [10-21.5]	11 [7.5-18]	.004
Cerebral perfusion time	15 [8.8-20.1]	13 [10-21.5]	15 [9-20.2]	.804	8.5 [6-16.5]	13 [10-21.5]	11 [7.5-18]	.003
ACP time	14.9 [9.8-19]	12 [9-20]	14 [9-20]	.735	14 [10-18]	12 [9-20]	12 [10-19.8]	.922
RCP time	6.8 [5-9.4]	3 [3-14]	6.7 [5-9.6]	.524	6.5 [5.7-8.1]	3 [3-14]	6.3 [5.6-8.2]	.446
Cerebral perfusion strategy				<.001				<.001
ACP only	35 (29.4%)	31 (91.2%)	66 (43.1%)		7 (20.6%)	31 (91.2%)	38 (55.9%)	
Both ACP and RCP	45 (37.8%)	2 (5.9%)	47 (30.7%)		6 (17.6%)	2 (5.9%)	8 (11.8%)	
RCP only	38 (31.9%)	1 (2.9%)	39 (25.5%)		21 (61.8%)	1 (2.9%)	22 (32.4%)	
Straight HCA only	1 (0.8%)	0 (0.0%)	1 (0.7%)		0 (0.0%)	0 (0.0%)	0 (0.0%)	
BACP (If ACP used)	64 (53.8%)	2 (5.9%)	66 (43.1%)	<.001	8 (23.5%)	2 (5.9%)	10 (14.7%)	.087
Dual perfusion after distal anastomosis	64 (53.8%)	6 (17.6%)	70 (45.8%)	<.001	8 (23.5%)	6 (17.6%)	14 (20.6%)	.764
Cooling time	49 [41-58]	45 [41.2-49.2]	48 [41-58]	.265	44 [33-58]	45 [41.2-49.2]	44 [35.5-57.5]	.813
Rewarming time	62 [45.8-81.2]	59.5 [44-73.8]	60 [45-81.2]	.710	67.5 [50-78]	59.5 [44-73.8]	60 [46.5-78]	.571
Multiple runs of bypass	4 (3.4%)	1 (2.9%)	5 (3.3%)	1.000	1 (2.9%)	1 (2.9%)	2 (2.9%)	1.000

Data are presented as median interquartile range or n (%). True redo patients had previous surgery involving the aortic root, ascending aorta, or arch. CABG, Coronary artery bypass grafting; CPB, cardiopulmonary bypass; XC, crossclamp; HCA, hypothermic circulatory arrest; ACP, antegrade cerebral perfusion; RCP, retrograde cerebral perfusion; BACP, bilateral antegrade cerebral perfusion.

TABLE 3. rSo₂ and intraoperative transfusions

Variable	Unmatched				Matched			
	Aortic (n = 119)	Innominate (n = 34)	Overall (N = 153)	<i>P</i> value	Aortic (n = 34)	Innominate (n = 34)	Overall (N = 68)	<i>P</i> value
rSO ₂								
Initial rSO ₂ left	69 [64-73]	69 [64.5-74.2]	69 [64-73]	.669	70 [67-74]	69 [64.5-74.2]	70 [65.5-74]	.607
Initial rSO ₂ right	69 [64-73]	67.5 [64.8-71.2]	68 [64-73]	.511	71 [67.5-73]	67.5 [64.8-71.2]	70 [66-73]	.152
Nadir rSO ₂ left	62 [58.5-66]	63.5 [53.5-68.2]	62 [58-67]	.987	63 [60-68.5]	63.5 [53.5-68.2]	63 [58-68.5]	.717
% Deviated from initial (baseline)	−7.6 [−14.1 to −1.4]	−9.9 [−14.5 to −2.1]	−8.7 [−14.3 to −1.4]	.697	−10.1 [−13.2 to −5.2]	−9.9 [−14.5 to −2.1]	−10.1 [−13.6 to −3.8]	.992
Nadir rSO ₂ right	62 [59-66.5]	62.5 [57.5-65.2]	62 [59-66]	.733	62 [61-65.5]	62.5 [57.5-65.2]	62 [59-65.5]	.608
% Deviated from initial (baseline)	−7.7 [−13.8 to −2.1]	−8.7 [−16.8 to −1.1]	−7.8 [−14.4 to −1.6]	.717	−10.1 [−13.8 to −6.1]	−8.7 [−16.8 to −1.1]	−9.3 [−14.9 to −4.4]	.562
End rSO ₂ left	68 [63-73]	67 [59.5-72]	68 [62.5-73]	.183	70 [66-75]	67 [59.5-72]	68 [65-73.5]	.021
% Deviated from initial (baseline)	0 [−9.1 to 7.4]	−4.8 [−9.8 to 0.3]	−1.5 [−9.3 to 5.1]	.072	1.4 [−4.8 to 7.7]	−4.8 [−9.8-0.3]	−2.8 [−7.3 to 1.9]	.015
End rSO ₂ right	67 [63-73]	67.5 [60.5-71.2]	67 [63-72]	.280	68 [64-72.5]	67.5 [60.5-71.2]	68 [63.5-72]	.445
% Deviated from initial (baseline)	−3 [−8.7 to 4.7]	−1.4 [−6.9 to 1.5]	−2.9 [−8.5 to 4.2]	.939	−3.3 [−9.2 to 0]	−1.4 [−6.9-1.5]	−2.9 [−8.2 to 0.7]	.423
Intraoperative blood transfusions								
pRBC	2 [0-4]	3 [0.2-8]	2 [0-5]	.223	2 [0-3.8]	3 [0.2-8]	2 [0-7]	.193
FFP	4 [1-6]	6 [4-8]	4 [2-6]	.001	3.5 [2-5]	6 [4-8]	4.5 [2.8-8]	.009
PLT	2 [2-3]	2 [2-3]	2 [2-3]	.520	2 [1.2-3]	2 [2-3]	2 [2-3]	.493
Cryo	0 [0-1]	0 [0-0]	0 [0-1]	.279	0 [0-1]	0 [0-0]	0 [0-1]	.353

Data are presented as median [interquartile range] or n (%). rSo₂, Regional cerebral oxygen saturation; pRBC, packed red blood cell; FFP, fresh-frozen plasma; PLT, platelets; Cryo, cryoprecipitate.

TABLE 4. Postoperative outcomes and follow-up status

Variable	Unmatched				Matched			
	Aortic (n = 119)	Innominate (n = 34)	Overall (N = 153)	P value	Aortic (n = 34)	Innominate (n = 34)	Overall (N = 68)	P value
Postoperative outcomes								
Encephalopathy/delirium	19 (16%)	4 (11.8%)	23 (15%)	.740	4 (11.8%)	4 (11.8%)	8 (11.8%)	1.000
Stroke	16 (13.4%)	5 (14.7%)	21 (13.7%)	.785	3 (8.8%)	5 (14.7%)	8 (11.8%)	.709
Atrial fibrillation	22 (18.5%)	7 (20.6%)	29 (19%)	.978	9 (26.5%)	7 (20.6%)	16 (23.5%)	.775
Acute kidney injury	8 (6.7%)	1 (2.9%)	9 (5.9%)	.685	0 (0.0%)	1 (2.9%)	1 (1.5%)	1.000
Renal failure requiring dialysis	8 (6.7%)	1 (2.9%)	9 (5.9%)	.685	0 (0.0%)	1 (2.9%)	1 (1.5%)	1.000
In-hospital death	9 (7.6%)	2 (5.9%)	11 (7.2%)	1.000	1 (2.9%)	2 (5.9%)	3 (4.4%)	1.000
Lost to follow-up with CT surgery within 1 year	53 (44.5%)	24 (70.6%)	77 (50.3%)	.013	17 (50%)	24 (70.6%)	41 (60.3%)	.137
Lost to follow-up with any CV provider within 1 year	39 (32.8%)	13 (38.2%)	52 (34%)	.698	14 (41.2%)	13 (38.2%)	27 (39.7%)	1.000

Data are presented as n (%). CT, Cardiothoracic; CV, cardiovascular.

cannulation in the 2010s and more recently toward preferential use of direct aortic cannulation since 2019. We thought direct aortic cannulation could streamline the CPB without the need for sewing a graft to the innominate artery. Peripheral cannulation is reserved for cases in which access to the innominate artery, ascending aorta, or proximal arch is limited or when safe entry into the chest cannot be achieved during redo sternotomy. Thus, the present study focuses specifically on systemic arterial cannulation for CPB initiation, independent of cerebral perfusion strategy.

Among patients undergoing redo sternotomy for aortic aneurysm repair, direct aortic versus innominate cannulation for CPB had similar rates of postoperative neurologic complications, in-hospital mortality, and long-term survival, despite heterogeneity in cerebral perfusion strategies. At our institution, cerebral protection has been guided by the Shaggy Aortic Protocol in the recent years,²⁰ incorporating brief RCP followed by ACP, for cerebral perfusion, regardless of the initial CPB arterial inflow site. When direct AC was used, ACP was established via the innominate artery using either a graft or direct cannulation. Bilateral ACP would be achieved using a trifurcated “Head First” graft when debranching was required in partial or total arch cases. RCP was initiated through the superior vena cava, with confirmation of deoxygenated venous return from the innominate and left common carotid arteries. Except for 2 cases in which the innominate artery was cannulated directly, all innominate cannulation cases were performed using an interposition graft.

To evaluate whether cannulation strategy independently affected the risk of postoperative stroke, multivariable logistic regression adjusting for repair urgency and extent of aortic arch replacement was performed. Partial or total arch replacement showed a borderline independent association with postoperative stroke ($P = .051$), suggesting

that procedural complexity and arch manipulation, rather than the specific central cannulation site, drive neurologic risk in redo aortic surgery.

Previous studies have primarily compared direct aortic and axillary (or subclavian) cannulation in the setting of acute type A aortic dissection (TAAD).^{8,13,21} When innominate and axillary cannulation have been compared, these studies have largely focused on their use for selective ACP rather than for CPB initiation,¹⁵⁻¹⁷ with 2 studies directly compared between innominate and axillary cannulation as bypass inflow.^{18,19} However, direct comparisons between direct aortic and IC for bypass initiation have been limited in the existing literature, particularly in redo aortic surgery.

Innominate Versus Axillary Cannulation

Innominate artery cannulation has most often been compared with axillary cannulation in the existing literature. Notably, in some previous studies, innominate cannulation was described as a strategy for SACP rather than for CPB initiation, with bypass typically established via central aortic cannulation.¹⁵⁻¹⁷ For instance, the CardioLink-3 randomized trial demonstrated noninferior neuroprotection with SACP via innominate versus axillary cannulation during elective proximal aortic surgery based on diffusion-weighted magnetic resonance imaging.¹⁵ It is important not to conflate the findings of those studies with the use of innominate cannulation for CPB arterial flow.

When used as arterial inflow for bypass, innominate artery cannulation offers a large-caliber conduit that provides less resistance to high-flow bypass and facilitates selective ACP, avoids an additional incision, and may reduce aortic manipulation.^{19,22} In this setting, innominate cannulation has shown stroke and mortality rates comparable with axillary cannulation,^{18,19} whereas it may offer shorter CPB and circulatory arrest times and less coagulopathy.¹⁹ Taken

TABLE 5. Logistic regression analysis for postoperative stroke

Variable	Univariable			Multivariable		
	Odds ratio	CI	P value	Odds ratio	CI	P value
Innominate cannulation (vs aortic cannulation)	1.11	0.375-3.286	.851	1.499	0.427-5.262	.528
Urgent/emergent presentation	2.643	0.953-7.330	.062	2.839	0.967-8.331	.057
Partial/total arch replacement	2.508	0.868-7.249	.09	3.213	0.996-10.360	.051

together, these data support innominate cannulation as a safe alternative to axillary cannulation.

Direct Aortic Versus Axillary Cannulation

Similarly, direct aortic cannulation has most often been compared with axillary access in previous studies. Compared with ascending aortic or proximal arch cannulation, axillary cannulation often requires longer CPB and XC times, which may increase anesthetic and hemodynamic risks in patients who are unstable.^{8,23} Multiple large series have found no differences in mortality or stroke between axillary and aortic cannulation in acute type A dissection, as well as in a smaller retrospective study of hemiarch

procedures.^{8,12-14} In contrast, an analysis of the European Registry of TAAD suggests that direct aortic cannulation may facilitate early restoration of true-lumen perfusion, lowering the incidence of permanent spinal cord injury, in-hospital morbidity, and mortality compared with supra-aortic cannulation (innominate, subclavian, or axillary) with similar stroke rates in primary TAAD repairs.²⁴ Conversely, another observational study reported lower early embolic stroke and mortality with axillary cannulation compared with nonaxillary approaches.²⁵ Overall, the literature suggests that central aortic cannulation is a safe strategy in appropriately selected patients with suitable anatomy.

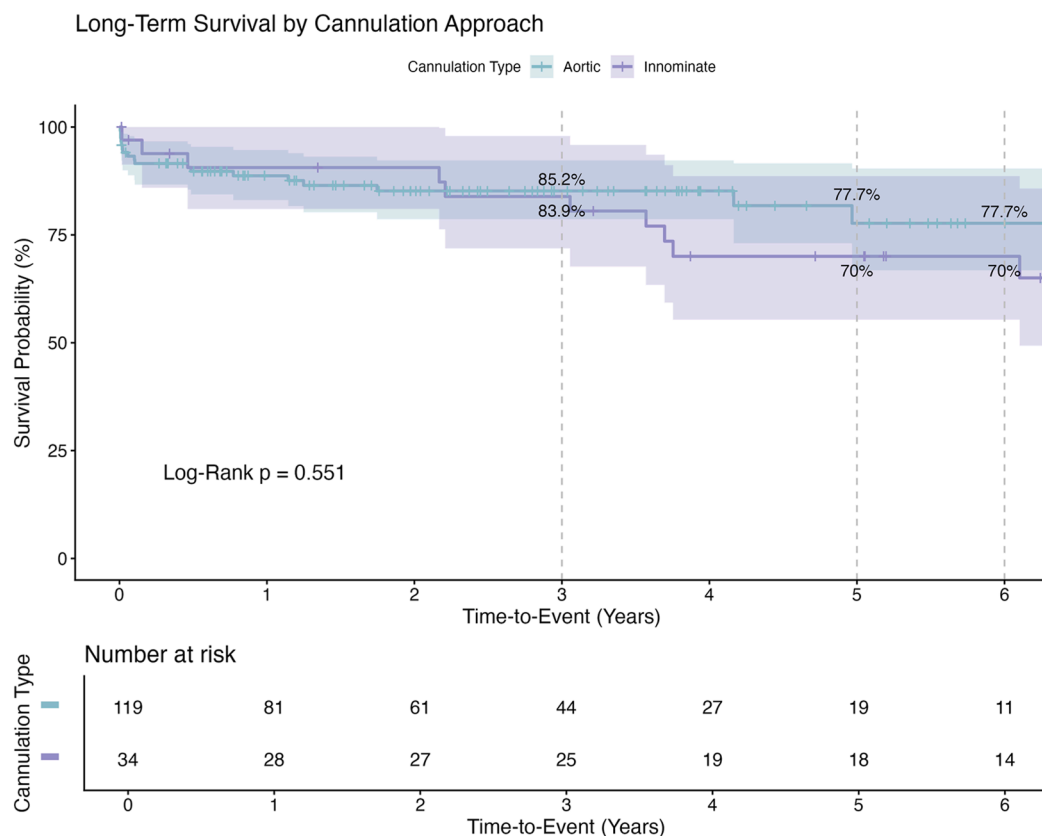


FIGURE 2. Kaplan-Meier estimated survival through 6 years after reoperative sternotomy and aortic aneurysm repair. Three-year survival rate was 85.2% for AC and 83.9% for IC, and five-year survival rate was 77.7% for AC and 70% for IC (log-rank $P = .551$). Shaded areas represent 95% CIs. Survival curves were truncated at 6 years, when the number at risk was $\geq 10\%$. AC, Aortic cannulation; IC, innominate artery cannulation.

Direct Aortic Versus Innominate Cannulation Considerations

Both direct aortic and innominate cannulation establish central antegrade arterial inflow, avoid retrograde systemic perfusion and an additional incision, and provide reliable cerebral protection using antegrade, retrograde, or combined strategies tailored to atherosclerotic burden, anatomy, and extent of repair. In our experience, both cannulation strategies were performed after safe exposure of the chest, with the choice of inflow site guided by the degree of mediastinal adhesions and ease of exposure, the quality of the native ascending aorta and innominate artery, the location of previous grafts or anastomoses, surgeon preference, and the planned cerebral protection strategy. Some surgeons preferentially used direct aortic cannulation, whereas others favored innominate cannulation. Direct aortic cannulation was required when RCP was planned. In addition, innominate cannulation may reduce aortic manipulation when atheromatous or calcific disease is present and facilitate the use of ACP. When innominate cannulation is selected, cannulation through a side graft is preferred. This may be particularly important in patients who are unstable and require rapid initiation of CPB because of ongoing bleeding during reentry.

In our redo cohort, neurologic risk was driven primarily by the extent of arch repair and procedural complexity; therefore, modest differences in the precise site of central inflow were unlikely to meaningfully affect cerebral embolic burden or perfusion quality when standardized systemic and cerebral perfusion protocols were used.

In PSM-adjusted data, the greater nadir temperature observed with direct aortic cannulation likely reflect changes in CPB protocol rather than the effect of cannulation site alone. Since late 2010s, our practice has shifted toward a target temperature of 28 °C for circulatory arrest in most aortic repairs, occurring alongside increased use of direct aortic cannulation. The shorter circulatory arrest time observed with aortic cannulation may reflect greater surgeon experience with complex aortic surgery and increasing use of the trifurcated “Head First” graft debranching approach for total arch replacement.²⁶

Cannulation in Redo Sternotomy

Despite the low incidence of reentry injury associated with redo sternotomy, the sequelae of an injury can be catastrophic.³ Preoperative computed tomography is pivotal in reducing the risk of injury.³ In our redo cohort including aortic and innominate cannulation, injury as the result of reentry was uncommon (1.3%), and CPB was established after exposure of the chest. One patient sustained an innominate vein injury, and one had an aortic entry; both were repaired directly without further operative sequelae. Although our analysis focuses on central cannulation strategies after

chest reentry, previous redo sternotomy literature has largely focused the timing and feasibility of establishing CPB, often contrasting presternotomy peripheral versus central cannulation to mitigate reentry risk.

Hosseini and colleagues⁵ described a technique of presternotomy innominate cannulation with femoral venous return in patients undergoing redo with limited space between the aorta and the sternum, reporting no cannulation-site complications or stroke, despite 2 in-hospital deaths due to aortic graft infection and multiorgan failure. Kuralay and colleagues²⁷ reported that establishing CPB via peripheral cannulation before resternotomy significantly shortened total operative time, decreased risk of cardiac/aortic injuries, reduced transfusion need and intensive care unit stay compared with classic CPB using central cannulation after reopening the chest. The Cleveland Clinic group found that early CPB (before resternotomy) was associated with significantly fewer major reentry injuries and shorter myocardial ischemic times than late CPB (established after resternotomy) in patients with low anatomic risk, whereas these outcomes were similar between strategies in the high-anatomic-risk cohort. Furthermore, total operative time and mortality were generally comparable between early and late CPB groups. In contrast, Brown and colleagues²⁸ reported that central cannulation had survival benefits with shorter operative times compared with presternotomy peripheral cannulation, which was selected in the setting of high-risk preoperative imaging findings or concern for injury during redo sternotomy, although these patients more frequently presented with urgent or emergent pathology. These studies underscore that redo sternotomy risk is driven primarily by reentry anatomy and timing of CPB initiation; in contrast, our findings address the choice between central antegrade inflow sites once chest exposure has been safely achieved.

Practice Consideration

Direct aortic cannulation may be used as an alternative to innominate cannulation in appropriately selected redo aortic surgery with no differences in cerebral and long-term survival outcomes. Selection between the 2 central inflow strategies should be guided by careful assessment of aortic and supra-aortic vessel disease, mediastinal adhesions, previous aortic reconstruction, surgeon experience, and the cerebral perfusion method in circulatory arrest cases.

Study Limitations

This study has several limitations. First, the retrospective, single-center design may introduce selection bias, as cannulation technique was nonrandom and influenced by surgeon preference and changes in practice and perfusion strategy over time, which may not have been fully accounted for by PSM. Second, the overall sample size limited statistical

power to detect small differences and to explore interactions among the extent of arch intervention, perfusion modality, and cannulation site. Larger, multicenter prospective studies would better validate these findings. Third, detailed data regarding previous aortic pathology, previous operative and reconstruction details, interval from the previous operation to the index reoperation, and number of previous sternotomies were not uniformly available, particularly for patients whose previous operations were performed at outside institutions. The presence and extent of supra-aortic branch dissection were not specifically assessed among patients with a history of type A aortic dissection repair. Fourth, detailed data on atheroma burden and intra-operative vessel quality were not uniformly available. Fifth, transfusion was mainly guided at the discretion of anesthesia and perfusion teams, with surgeons providing additional input during ongoing bleeding. Sixth, there were approximately 26% of patients who had missing data on cooling/rewarming times and oximetry, which may limit interpretation of these data. Lastly, a prospective study incorporating standardized preoperative imaging and intra-operative ultrasound to assess quality of branch vessel, and transcranial Doppler monitoring would provide a more comprehensive comparison of cerebral embolic burden and neurologic outcomes between cannulation strategies.

CONCLUSIONS

Among patients undergoing redo sternotomy for aortic aneurysm repair, direct aortic and innominate cannulations demonstrated comparable postoperative neurologic outcomes and long-term survival. Postoperative stroke showed a borderline association with more extensive arch replacement, reflecting increased operative complexity and arch manipulation, rather than with operative urgency or cannulation site. These findings support the safety of both direct and innominate cannulation for CPB in redo aortic surgery.

Conflict of Interest Statement

J.C.C. serves as a consultant and a study principal investigator for Abbott. M.A. serves as a consultant for W. L. Gore & Associates, Artivion Inc, Bolton Inc, and AngioDynamics. T.B.R. serves as a consultant for W. L. Gore & Associates, Terumo Aortic, Artivion Inc, and Corcym, Inc. 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.

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Key Words: aortic cannulation, innominate cannulation, cardiopulmonary bypass, redo sternotomy, reoperation