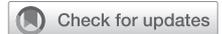


# A simple method to establish antegrade cerebral perfusion during hemiarch reconstruction



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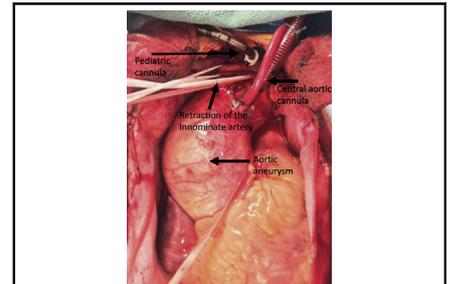
## ABSTRACT

**Objective:** We describe a novel and safe technique using a 12F–14F pediatric arterial cannula to establish unilateral, selective, antegrade cerebral perfusion (ACP) during open hemiarch reconstruction.

**Methods:** Between January 2015 and September 2018, 42 patients underwent elective aortic aneurysm repair requiring an open distal anastomosis and at least a hemiarch replacement via hypothermic circulatory arrest by 2 surgeons. All distal reconstructions were performed at moderate hypothermia (22°C–26°C) with direct cannulation of the innominate artery (IA) using a pediatric arterial cannula to allow ACP at 10–15 mL/kg/min. Data were collected by retrospective chart review.

**Results:** Thirty-one of the 42 patients (74%) were male. The mean patient age was 65 ± 13 years, and the mean body surface area was 2.1 ± 0.3 m<sup>2</sup>. Proximal repairs included a modified Bentall with a valve-graft composite (n = 17), valve-sparing root replacement (n = 2), and aortic valve replacement (n = 15). Perioperative mortality was 2% (n = 1), and the incidence of stroke was 0%. The mean lowest core body temperature reached during circulatory arrest was 23.8 ± 2.7°C with a mean ACP time of 21.8 ± 3.6 minutes. The mean aortic cross-clamp and cardiopulmonary bypass times were 160.6 ± 55.5 minutes and 204.7 ± 57.5 minutes, respectively. There were no cases of IA injury.

**Conclusions:** Direct IA cannulation with a pediatric arterial cannula is a safe and efficient method to allow ACP in aortic surgery requiring hypothermic circulatory arrest and may circumvent the potential complications of axillary cannulation. (JTCVS Techniques 2020;2:10-5)



Intraoperative view of innominate artery and central aortic cannulation.

## CENTRAL MESSAGE

Direct innominate artery cannulation with a pediatric arterial cannula is a safe and efficient method to allow antegrade cerebral perfusion in aortic surgery requiring hypothermic circulatory arrest.

## PERSPECTIVE

Aortic arch surgery requiring hypothermic circulatory arrest has traditionally been accomplished using right axillary artery cannulation either directly or via a side graft for cerebral perfusion. We present a safe, simple, and effective method for direct innominate artery cannulation with excellent short-term outcomes which may circumvent the potential complications of axillary cannulation.

See Commentaries on pages 16 and 18.

Video clip is available online.

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Complex aortic arch surgery often requires an open distal anastomosis, which carries an inherent risk of neurologic injury. Protective strategies to mitigate these complications include systemic hypothermia, minimizing the circulatory arrest time, and providing some means of cerebral blood flow. Although there is some variability as to whether this cerebral blood flow should be antegrade versus retrograde, or unilateral (via the right carotid artery) versus bilateral (via both carotid arteries), most consensus guidelines

### Abbreviations and Acronyms

ACP	= antegrade cerebral perfusion
CPB	= cardiopulmonary bypass
HCA	= hypothermic circulatory arrest
IA	= innominate artery

recommend antegrade cerebral perfusion (ACP) via axillary artery cannulation for aortic arch surgery.<sup>1,2</sup>

ACP usually involves sewing a graft to the axillary artery in conjunction with moderate to deep hypothermia, and has proven to be a safe and effective method.<sup>3,4</sup> However, this technique requires an additional incision and is subject to such complications as brachial nerve injury, seroma formation, aortic dissection, and limb ischemia.<sup>5,6</sup> Here we report a novel and reproducible method using direct cannulation of the innominate artery (IA) via a 12F or 14F pediatric arterial cannula, after median sternotomy, to establish ACP for elective repair of aortic aneurysms requiring a period of moderate hypothermic circulatory arrest (HCA).

## METHODS

### Patients

Between January 2015 and September 2018, 42 patients underwent aortic replacement requiring an open distal anastomosis under moderate HCA with ACP established by direct IA cannulation. Two cardiac surgeons performed all of the operations. Data were collected by retrospective chart review. Baseline patient characteristics are listed in Table 1. Intraoperative data, including type of aortic repair, cardiopulmonary bypass (CPB) and cross-clamp times, as well as the lowest core body temperature, are provided in Table 2. All operations were performed electively. Patients undergoing urgent or emergent repair due to type A aortic dissections, aortic hematomas, or infective endocarditis were excluded from the study. The study protocol was approved by the Institutional Review Board of Spectrum Health (approval 2018-178; 8/2/2018).

### Intraoperative Monitoring

In addition to standard anesthesia monitoring, patients received either a right or bilateral radial arterial line(s). Swan-Ganz catheters were not used routinely, in accordance with the established protocol of our medical practice group. In all patients, direct cardiac imaging guidance was provided by transesophageal echocardiography. Cerebral perfusion was monitored using near-infrared spectroscopy (Somanetics; Covidien, Mansfield, Mass). Cerebral oximetry values were recorded at baseline and throughout the operation. Significant decreases (>50%) in oximetry values during the period of circulatory arrest prompted an increase in cerebral blood flow via the IA cannula.

### Operative Technique

Following median sternotomy and full systemic heparinization, the innominate vein is mobilized with a vessel loop and retracted cephalad to allow exposure to the IA. The base of the IA is then dissected and mobilized to allow an umbilical tape to be passed around it (Figure 1, A). A single purse-string suture is then placed on the anterior surface of the IA approximately 1 cm distal to its origin using a 5-0 Prolene suture. A needle and 0.035 J guidewire is then placed in the IA, and the 12F or 14F (22.9 cm long) pediatric arterial cannula (Bio-Medicus; Medtronic, Minneapolis, Minn) (Figure 2) is placed over the guidewire without the need for

TABLE 1. Baseline patient and operative characteristics

Characteristic	Value
Age, y, mean ± SD	65 ± 13
Male sex, n (%)	31 (74)
Smoker, n (%)	29 (69)
Hypertension, n (%)	35 (82)
Dyslipidemia, n (%)	21 (50)
Chronic lung disease, n (%)	3 (7)
Type II diabetes, n (%)	5 (12)
Renal failure, n (%)	4 (10)
Serum creatinine, mg/dL, mean ± SD	1.2 ± 1.0
Previous stroke, n (%)	3 (7)
Previous myocardial infarction, n (%)	2 (5)
Ejection fraction, %, n (%)	
≤30	2 (5)
31 ≤45	6 (14)
>45	34 (81)
NYHA score ≥3, n (%)	10 (24)
BMI, kg/m <sup>2</sup> , mean ± SD	30.0 ± 6.0
BSA, m <sup>2</sup> , mean ± SD	2.1 ± 0.3
Weight, kg, mean ± SD	93 ± 21
Largest aortic diameter by CT, cm, mean ± SD	5.3 ± 0.7
Bicuspid aortic valve, n (%)	19 (45)

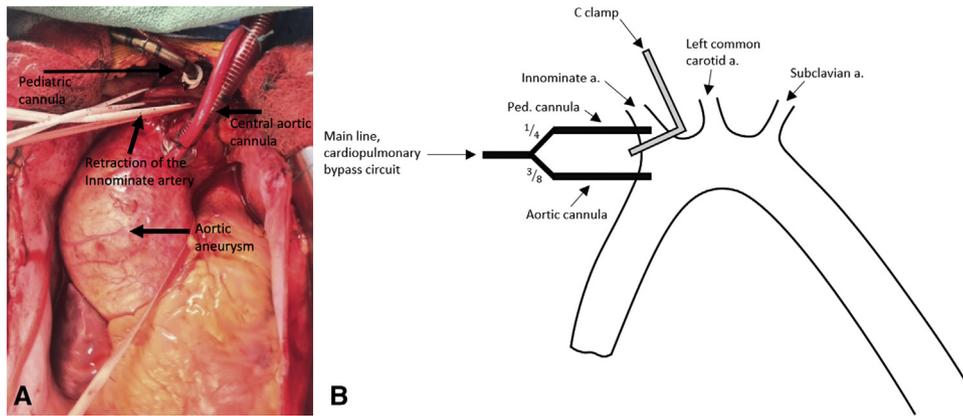
SD, Standard deviation; NYHA, New York Heart Association; BMI, body mass index; BSA, body surface area; CT, computed tomography.

predilation (Figure 1, A). This cannula is placed at a depth of only 1–1.5 cm into the vessel. The arterial line of the bypass circuit is spliced using a 3/8-, 3/8-, 1/4-in Y-connector, with the 1/4-in portion connected to the pediatric cannula and the 3/8-in portions connected to the aortic cannula. A

TABLE 2. Intraoperative Results

Parameter	Value
Procedure type, n	
Ascending aorta/hemiarch replacement	42
Ascending aorta/hemiarch replacement + modified Bentall	17
Ascending aorta/hemiarch replacement + VSRR	2
Ascending aorta/hemiarch replacement + AVR	15
Ascending aorta/hemiarch replacement + CABG	9
Intraoperative times, minutes, mean ± SD	
CPB time	204.7 ± 57.5
Cross-clamp time	160.6 ± 55.5
ACP time	21.8 ± 3.6
Cerebral blood flow, mL/kg/min, mean ± SD	
12F cannula	13.0 ± 2.6
14F cannula	11.2 ± 2.5
Lowest core temperature, °C, mean ± SD	23.8 ± 2.7

VSRR, Valve-sparing root replacement; AVR, aortic valve replacement; CABG, coronary artery bypass grafting; SD, standard deviation; CPB, cardiopulmonary bypass; ACP, antegrade cerebral perfusion.



**FIGURE 1.** Intraoperative view of the innominate artery (IA) and central cannulation with schematic diagram of the bypass circuit during antegrade cerebral perfusion (ACP). A, The aortic aneurysm is cannulated in standard fashion while the IA is cannulated with a 12F or 14F pediatric cannula. B, Schematic diagram of ACP with the main arterial line spliced to the central aortic cannula via a 3/8-inch line and to the pediatric cannula via a 1/4-inch line with cross-clamping of the base of the IA.

clamp is placed on the 1/4-in tubing. The ascending aorta (usually in the aneurysmal portion that will be resected) and right atrium are then cannulated in the usual fashion. The patient is then placed on CPB, and systemic cooling is initiated to achieve a bladder temperature of 21°C–26°C. A retrograde cardioplegic catheter and a left ventricular vent are placed at the surgeon's discretion. The aortic cross-clamp is then placed, and the heart is arrested in the usual fashion. The proximal aortic work, in addition to any valve replacement or coronary artery bypasses, are performed while the patient is being cooled.

Once the target core temperature is reached, the patient is placed in deep Trendelenburg position. Caudal traction of the umbilical tape is applied to allow placement of a DeBakey vascular clamp to the base of the IA. The 1/4-in tubing is now unclamped, and a clamp is placed on the 3/8-in tubing to the main aortic cannula, thereby allowing blood flow solely to the pediatric cannula (Figure 1, B). Circulatory arrest is initiated with ACP with blood flow provided to the IA via the 12F/14F cannula at 10–15 mL/kg/min while maintaining a right radial pressure of 50–70 mm Hg. The left carotid artery is clamped at the surgeon's discretion.

The aortic cannula is then removed, the aorta is resected, and the open distal aortic anastomosis is performed in standard fashion using a Gel-weave woven graft with an 8-mm side limb (Vascutek Terumo, Renfrewshire, Scotland). If left-sided cerebral oximetry values drop by 50% of the baseline value, then a soft balloon-tipped retrograde cannula is inserted into the left carotid artery and also perfused during the arrest period. No patient required antegrade perfusion of the left common carotid artery during the HCA period. Once the anastomosis is complete, the side limb of the graft is connected to the main arterial line of the bypass circuit. A clamp is placed on the 1/4-in tubing once again to stop ACP and prevent overperfusion of the right cerebral hemisphere, and the aortic cross-clamp is placed on the graft and full CPB flow is reinitiated via the side limb with systemic rewarming. The remaining proximal reconstruction is then completed during the rewarming phase (Video 1).



**FIGURE 2.** A 14F pediatric arterial cannula.



**VIDEO 1.** Operative technique for innominate artery cannulation and the conduct of hypothermic circulatory arrest with antegrade cerebral perfusion. Video available at: [https://www.jtcvs.org/article/S2666-2507\(20\)30160-7/fulltext](https://www.jtcvs.org/article/S2666-2507(20)30160-7/fulltext).

## RESULTS

The baseline patient characteristics are listed in Table 1. The mean patient age was  $65 \pm 13$  years, and 74% of the cohort was male. The patients had a mean body surface area of  $2.1 \pm 0.3$  m<sup>2</sup> and a mean body mass index of  $30.0 \pm 6.0$  kg/m<sup>2</sup>. The largest mean aortic diameter before surgery was  $5.3 \pm 0.7$  cm.

Intraoperative details are provided in Table 2. In addition to a hemiarch replacement, 19 patients also had an aortic root procedure, and 15 patients had a concomitant aortic valve replacement. The mean CPB times, mean aortic cross-clamp times, and mean HCA times were  $205 \pm 58$  minutes,  $161 \pm 56$  minutes, and  $22 \pm 4$  minutes, respectively. The lowest mean core body temperature was  $24 \pm 3$  °C. Mean cerebral blood flow exceeded 10 mL/kg/min for both the 12F and 14F arterial cannulas. There were no complications related to insertion of the innominate cannula.

In our series, none of the patients suffered a clinical stroke, and the mean hospital stay was  $12 \pm 13$  days. The overall perioperative mortality was 2% (Table 3). The single death occurred in an 82-year-old man who initially refused surgery for worsening aortic valve regurgitation until he was admitted to the hospital with New York Heart Association class IV heart failure. His aortic root measured <4.5 cm, but his ascending diameter measured 5.1 cm by computed tomography tapering into the proximal arch. He underwent uneventful aortic valve replacement and ascending aorta and hemiarch replacement. However, on postoperative day 2, he developed hypotension with acute right ventricular failure. Repeat left heart catheterization demonstrated acute occlusion of the distal posterior descending coronary. A right-sided Impella (Abiomed, Danvers, Mass) was inserted. He died on postoperative day 8 from an inferior vena cava laceration after Impella removal.

**TABLE 3. Postoperative outcomes**

Outcome	Value
30-day/in-hospital mortality, n (%)	1 (2)
Stroke, n	0
Intensive care unit length of stay, d, mean $\pm$ SD	$4.6 \pm 10.6$
Hospital length of stay, d, mean $\pm$ SD	$11.7 \pm 13.1$
Ventilator for >24 h, n (%)	5 (12)
Tracheostomy, n (%)	2 (5)
Atrial fibrillation, n (%)	23 (55)
Renal failure necessitating dialysis, n (%)	3 (7)
Permanent pacemaker, n	0
Reoperation for bleeding, n (%)	3 (7)
Need for blood transfusion, n (%)	8 (19)

SD, Standard deviation.

## CONCLUSIONS

Several strategies have evolved over the years to improve neuroprotection during aortic arch surgery. Deep HCA alone was initially used as the primary mode of brain protection, followed by the introduction of retrograde cerebral blood flow in conjunction with HCA. Later, the Cleveland Clinic demonstrated the advantages of axillary artery cannulation via a side graft not only in hostile aortas, but also for allowing ACP during aortic arch surgery.<sup>5,6</sup> Further evidence has revealed that ACP allows for more uniform cerebral blood flow and a longer period of safe circulatory arrest time, and also permits the use of moderate hypothermia, thereby shortening the cooling and rewarming phases.<sup>7-9</sup> These advantages have prompted guidelines to support the use of ACP via the axillary artery for complex aortic surgery.<sup>1,10</sup> However, axillary artery cannulation requires additional operative time and can entail potential complications, including seroma or hematoma formation, brachial plexus injury, limb malperfusion, and aortic dissection.<sup>11-14</sup>

Compared with axillary cannulation, direct cannulation of the IA may reduce the operative time as well as decrease the inherent risk of complications. Various methods have been described for cannulation of the IA in the setting of aortic arch surgery. Preventza and colleagues<sup>15</sup> reported their outcomes in 938 patients using an 8-mm side graft sewn to the IA to establish CPB as well as ACP during aortic arch surgery at moderate HCA.<sup>15</sup> Their results were acceptable, with an overall mortality rate of 4.9% and a stroke rate of 3.4%. This same group subsequently published their outcomes comparing 515 patients undergoing right axillary cannulation with 376 patients with IA cannulation (both with a side graft), in elective aortic cases.<sup>16</sup> There was no difference in operative mortality or overall stroke rate with respect to the cannulation strategy, and there were no complications related to the cannulation site. The University of Colorado also reported a similar study comparing axillary artery and IA cannulation, both via a side graft, in 206 patients undergoing elective hemiarch surgery.<sup>17</sup> Both operative mortality and the overall incidence of stroke were lower in the IA group. A similar technique for IA cannulation was also described by di Eusanio and colleagues,<sup>18</sup> with a resulting stroke rate of 0% in a series of 55 patients. It should be noted that sewing a graft to the IA requires a partial side clamp to the brachiocephalic artery to allow an anastomosis, which may potentially impair right cerebral blood flow as well as cause injury to the vessel.

Other reported methods for IA cannulation include placing a 22F–24F specifically designed angled cannula directly into the artery. The cannula is angled toward the arch to allow CPB and then rotated cranially before HCA to allow ACP. Shangyi and colleagues<sup>19</sup> described this method in 68 patients undergoing proximal aortic arch surgery, with 2 mortalities and no neurologic complications.

Hokanek and coworkers<sup>20</sup> also used this method in 39 patients with annuloaortic ectasia undergoing aortic root replacement with HCA and ACP. Temporary neurologic deficit was seen in 5 cases, with 2 operative deaths. Although there were no reportable complications attributable to the cannula in these series, introducing such a large cannula into the IA may injure the back wall of the vessel and limit use only to patients with larger arteries. Furthermore, rotating a 24F cannula to allow HCA may also risk vascular injury and dissection.

In the present study, we placed a flexible 12F or 14F pediatric arterial cannula (Medtronic Bio-Medicus) into the IA over a guidewire using a modified Seldinger technique without the need for predilation. This cannula is used only for ACP, and thus subsequent manipulation of the cannula is not required. The aneurysmal aorta is then cannulated in usual fashion for CPB and later resected. This small cannula may be placed in any size IA. During our initial experience we used a 14F cannula for most patients, particularly those >100 kg, to maintain a cerebral blood flow of 10–15 mL/kg/min during the circulatory arrest period. However, later we began also using a 12F cannula and obtained similar flows for similar-sized patients. The advantage of this technique over other previously described methods for ACP is that it is quick and easy to perform. It avoids the need to sew a graft and also avoids the inherent issues and added complexity of axillary cannulation. Furthermore, compared with ostial IA cannulation, which is typically performed with a balloon-tipped catheter, our method avoids any interruption in cerebral blood flow and removes any clutter out of the aorta during the distal anastomosis. Moreover, none of our cases required division of the innominate vein for exposure. In a recent systematic review of IA cannulation during thoracic surgery, the technique was deemed safe and reliable.<sup>21,22</sup>

Garg and colleagues<sup>23</sup> reported a similar technique to our own, using a 14F pediatric venous cannula in the IA during hemiarch replacement under moderate HCA in 50 patients. Their results were comparable to our present findings, with 1 stroke and 1 operative mortality. However, 2 patients with tortuous arterial anatomy failed to undergo IA cannulation using their technique. The pediatric cannula used in our study has no side ports and has a very tapered introducer sheath. This design obviates the need for predilation and requires insertion of only the distal tip into the IA, allowing access to even tortuous anatomy. Jasser et al<sup>24</sup> used a 9F cardioplegia cannula for 100 patients undergoing elective hemiarch reconstruction, and reported 1 operative death and 2 adverse neurologic outcomes. When using a small cannula in larger patients, achieving adequate cerebral perfusion might be challenging; however, the authors reported cerebral flows of 1.5 L/min during the HCA period. In our cohort of larger

patients (mean BSA of  $2.1 \pm 0.3 \text{ m}^2$ ), we obtained excellent flows even with the smaller 12F cannula.

Relative contraindications to the use of this technique would be severe proximal IA calcification or arterial dissection, which should be evaluated by preoperative imaging. We did not use this technique in acute aortic dissections, for which our preferred method is axillary artery cannulation via a side graft. Introducing a catheter into a potentially dissected IA could lead to false lumen perfusion and, ultimately, brain malperfusion.

A limitation of this study is our limitation of this technique for elective aortic arch reconstructions. As mentioned above, employing this technique in emergent aortic dissections could have potential pitfalls. In addition, we only use this technique with moderate hypothermia. Performing an open distal aortic anastomosis at higher temperatures may reduce the time required to cool and rewarm the patient and subsequently reduce the CPB times. Moreover, all of the operations in this study included relatively simple hemiarch replacements, although more complex aortic operations such as zone 2 and 3 repairs could also be performed using this technique for cerebral protection.

Aortic arch surgery requiring a period of HCA has traditionally been accomplished using right axillary artery cannulation for cerebral perfusion. More recently, direct cannulation of the IA has emerged as an alternative site for cannulation. Here we present a safe, simple, and effective method for direct IA cannulation using a 12F–14F pediatric cannula with excellent short-term results.

### Conflict of Interest Statement

The 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:** circulatory arrest, antegrade cerebral perfusion, aortic surgery, innominate artery