

Cannulation of the Innominate Artery With a Side Graft in Arch Surgery

Fang Jiong Huang, MD, Qiang Wu, MD, Chang Wei Ren, MD, Yong Qiang Lai, MD, Sheng Yang, MD, Qi Jin Rui, MD, and Shang Dong Xu, MD

Cardiac Surgery Division, Beijing Institute of Heart, Lung and Vascular Diseases, Capital Medical University, Beijing Anzhen Hospital, Beijing, China

Background. The purpose of this study was to examine the safety and efficacy of cannulation of the innominate artery with a side graft in arch surgery.

Methods. Between January 2004 and March 2009, 46 patients received arch surgery under hypothermia circulatory arrest (HCA) and hemispheric antegrade cerebral perfusion (HACP). There were 36 men and 10 women with an average age of 48.0 ± 12.8 years. Thirty-four patients had type A aortic dissection. Four patients had type B aortic dissection. The remaining 8 patients had aortic aneurysm involving the ascending aorta and arch. The innominate artery was free of diseases in all patients. The diameter of the innominate artery was 12.1 ± 1.6 mm (range, 9 to 16 mm). An 8-mm vascular graft, which was anastomosed to the innominate artery in an end-to-side manner, was used for arterial cannulation. Ascending aorta and arch replacement in combination with open stent-graft implantation was conducted in 42 patients.

Four patients received open stent-graft implantation through the aortic arch only.

Results. The aortic cross-clamp time was 87.2 ± 36.0 minutes. The lowest nasopharyngeal temperature was $21.0 \pm 3.6^\circ\text{C}$. The HCA and the HACP time was 29.6 ± 14.0 minutes. The HACP flow was $8.3 \pm 2.3 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Five patients (10.9%) had temporary postoperative neurologic dysfunction. There was no permanent neurologic dysfunction. Three patients died within 30 days postoperatively, and the 1-month mortality rate was 6.5%. All of the surviving patients were followed for 24.9 ± 18.0 months (range, 1 to 63). There were no deaths or severe complications during the follow-up.

Conclusions. Cannulation of the innominate artery with a side graft is safe and effective in arch surgery.

(Ann Thorac Surg 2010;89:800–4)

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Despite recent advances in surgical techniques and cerebral protection methodologies, temporary neurologic dysfunction (TND) or permanent neurologic dysfunction (PND) remain the major cause of morbidity and mortality after aortic arch surgery [1, 2]. Hypothermia circulatory arrest (HCA) only or HCA with retrograde cerebral perfusion (RCP) has become less widely used. Instead, HCA with antegrade cerebral perfusion (ACP) is now used in the majority of cardiac centers [3]. The right axillary artery has become a favorable choice for arterial cannulation. However, this technique requires an extra incision beside the median sternotomy to expose the right axillary artery.

Between January 2004 and March 2009, 46 patients underwent arch surgery using the innominate artery perfusion technique in our institute. The median sternotomy was the only incision. Here, we report the results of these procedures.

Material and Methods

Of the 46 patients, 36 were men and 10 were women, with mean age of 48.0 ± 12.8 years (range, 18 to 74). Thirty-four patients had type A aortic dissection, and 4 patients had type B dissection. The remaining 8 patients had an ascending aortic aneurysm with arch involvement. Fifteen patients also had aortic regurgitation. The inclusion criteria for this analysis included (1) patient needing arch surgery, and (2) that the innominate artery is free of diseases including dissection or severe atherosclerotic changes. Informed consent was obtained from each patient. The study was approved by the Ethics Committee of our center. All patients received computed tomography angiography or magnetic resonance angiography before the operation. The innominate artery was confirmed to be normal on computed tomography or magnetic resonance angiography in all patients. The diameter of the innominate artery was also measured on the computed tomography or magnetic resonance angiography scan and was 12.1 ± 1.6 mm (range, 9 to 16 mm). The patients' characteristics are listed in Table 1.

Surgical Procedure

General anesthesia was used in all patients. Arterial blood pressure was monitored by right radial arterial line and dorsal arterial line of unilateral foot. Nasopharyngeal and

Accepted for publication Dec 2, 2009.

Address correspondence to Dr Xu, Cardiac Surgery Division, Beijing Institute of Heart, Lung and Vascular Diseases, Capital Medical University, Beijing Anzhen Hospital, Beijing 100029, China; e-mail: xushangdong@vip.sina.com.

Table 1. Patients' Clinical Data

	Number (n = 46)	Percent
Sex		
Male	36	78.3
Female	10	21.7
Age, years	18-74	48.0 ± 12.8
Diagnosis		
Type A dissection	34	73.9
Type B dissection	4	8.7
True aneurysm	8	17.4
Aortic regurgitation	15	32.6
Hypertension	28	60.9
Marfan's syndrome	8	17.4
Innominate artery diameter, mm	9-16	12.1 ± 1.6
Ejection fraction, %	31-83	63.7 ± 10.7
Left ventricle end-diastolic diameter, mm	37-70	51.0 ± 7.5

rectal temperatures were monitored continuously. Median sternotomy was the only incision. The innominate vein was dissected up, off the aortic arch, and retracted caudally. Three arch branches including the innominate artery, the left carotid artery, and the left subclavian artery were mobilized. After systemic heparinization, the innominate artery was partially side-clamped by an inclusion clamp. The mean blood pressure of the right radial artery was maintained above 50 mm Hg. A 10-mm long incision was made in the innominate artery. An 8-mm vascular graft was anastomosed with the innominate artery in an end-to-side manner using a running 5-0 polypropylene suture. The side graft was then cannulated with a 24F arterial perfusion cannula (Fig 1). A two-stage cannula inserted into the right atrium was used for venous drainage. Left side of the heart drainage was through the superior right pulmonary vein.

Cardiopulmonary bypass (CPB) was then started. The aortic root lesion was repaired first. Bentall's operation was carried out in 14 patients. One patient underwent David's operation. When the rectal temperature

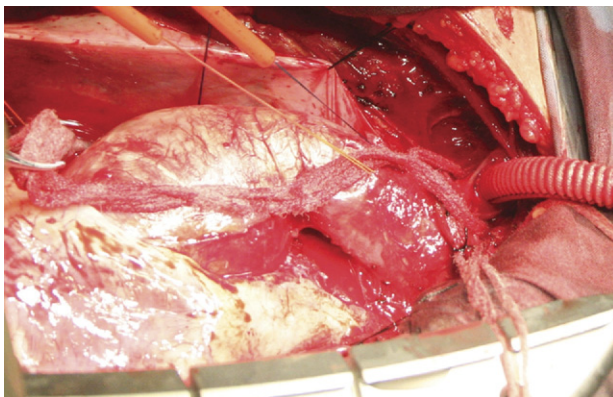


Fig 1. Image taken during operation. An 8-mm vascular graft is anastomosed to the innominate artery in an end-to-side manner, and was cannulated with a 24F arterial cannula.

Table 2. Clinical Scale for Temporary Neurologic Dysfunction

Grade		Duration
Grade 1	Simple confusion	Short (< 48 hours)
Grade 2	Confusion plus lethargy	Short
Grade 3	Confusion plus agitation	Short (< 72 hours)
Grade 4	Overt psychosis	Long (>72 hours)
Grade 5	Psychosis, parkinsonism	Long

reached 22° to 24°C, the perfusion flow was reduced to 5 to 12 mL · kg⁻¹ · min⁻¹, and all three arch branches were clamped at their respective origins. Hemispheric antegrade cerebral perfusion (HACP) was then started. The right radial artery pressure was maintained at 30 to 50 mm Hg, and the aortic arch was opened. Open stent-graft (Microport; Cronus, Shanghai, China) was deployed into the descending aorta in all patients under direct vision. In the 4 patients with type B dissection, the arch was then closed. In other patients, a four-branch vascular graft (Intervascular, La Ciotat, France) was anastomosed with the proximal end of the open stent-graft. Systemic CPB was then resumed by cannulation of the fourth branch of the vascular graft. The remaining three branches were connected with the left carotid artery, the innominate artery, and the left subclavian artery. Two patients with coronary artery disease also underwent simultaneous bypass surgery. After weaning off the CPB, decannulation was performed by amputation of the 8-mm vascular graft 5 mm from the anastomosis to the innominate artery. The stump was closed with a running 5-0 polypropylene suture. During cooling, pH-stat management was used, and the alpha-stat method of pH control was used for the rest of the CPB.

A PND was defined as stroke confirmed by conventional imaging techniques. A TND was defined as subtle but diffused brain injury and was classified into five grades ranging from simple confusion to psychosis (Table 2) [4]. A neurologist was asked to give each patient a neuropsychological evaluation postoperatively.

Results

All patients regained full consciousness postoperatively. Five patients (10.9%) had postoperative TND: 3 with grade 2 and 2 with grade 3. Confusion and agitation were the main manifestations. The duration of TND was less than 72 hours in each patient. There was no PND after the procedure. There were no postoperative complications related to innominate artery cannulation. Three patients died within 30 days after the operation owing to heart failure (n = 1), renal failure (n = 1), or infection (n = 1). The operative mortality was 6.5%. All 3 patients exhibited multiorgan failure before death. All of the surviving patients were followed for 24.9 ± 18.0 months (range, 1 to 63). There were no deaths or severe complications during the follow-up. One patient received replacement of abdominal aorta 4 years after the proce-

Table 3. Results

	Range	Mean \pm SD
Operative mortality, n	3	6.5 (%)
Lowest nasopharyngeal temperature, °C	11.9–27.7	21.0 \pm 3.6
Lowest rectal temperature, °C	8.0–31.4	23.6 \pm 4.4
Aortic cross-clamp time, minutes	11–174	87.2 \pm 36.0
Cardiopulmonary bypass time, minutes	75–363	166.4 \pm 51.4
Hypothermia circulatory arrest time, minutes	6–61	29.6 \pm 14.0
HACP flow, mL \cdot kg ⁻¹ \cdot min ⁻¹	5.8–12.5	8.3 \pm 2.3
Drainage, mL	120–3150	723.2 \pm 552.6
Mechanical ventilation time, hours	12–132	40.0 \pm 31.5
Intensive care unit time, hours	6–150	43.5 \pm 36.6
Hospital stay length, days	11–48	27.8 \pm 8.9
Follow-up time, months	1–63	24.9 \pm 18.0

HACP = hemispheric antegrade cerebral perfusion.

due because of an abdominal aortic aneurysm. The results are summarized in Table 3.

Comment

Some basic techniques and perfusion strategies have been established for aortic arch surgery, including HCA, ACP, and RCP. However, RCP is no longer used in many centers because studies have shown that only a trivial amount of blood flow enters the brain capillaries during RCP [5,6]. Current, HCA with ACP is a popular approach for brain protection during arch surgery. The right axillary artery is a favorable artery for arterial perfusion. Compared with femoral artery cannulation, right axillary artery cannulation reduces the risk of malperfusion, hypoperfusion, retrograde embolization, and retrograde dissections. At any time during the procedure, systemic CPB can be easily transferred to HACP.

Cannulation of the innominate artery in arch surgery was first reported by Banbury and Cosgrove [7] in 2000. Compared with right axillary artery cannulation, innominate artery cannulation has the following advantages. First, it eliminates the need for a second incision to gain access to the axillary artery. Second, because the innominate artery is usually larger than the right subclavian or axillary arteries, total CPB flow can be easily achieved without high pump pressures. Third, the HACP pressure can be monitored by a routine right radial arterial line. Finally, the risk for brachial plexus injury or right axillary artery injury can be avoided.

Cannulation of the innominate artery with a side graft was first reported by Di Eusanio and colleagues [8]. Direct cannulation of the innominate artery with a routine aortic cannula was then reported by Ji and coworkers [9]. Compared with a side graft, direct cannulation has some limitations. Direct cannulation of the innominate artery may cause damage to the artery. During the procedure, the tip of the cannula should be adjusted at least twice. During cooling and rewarming, the tip should be pointing toward

the arch, whereas during HCA, the tip should be oriented toward the head. After decannulation and tying of the purse-string, the innominate artery may become narrowed. Stassano and associates [10] reported a modified cannula designed for innominate artery cannulation. The right-angled cannula tip has two openings: one pointing toward the arch and one pointing toward the head. Therefore, the tip does not need to be adjusted during the procedure. Nevertheless, injury caused by direct cannulation cannot be completely avoided.

In this study, HACP was used. In as many as 15% of humans, there is an incomplete circle of Willis because of the absence of one of three communicating arteries [11]. During HACP, we open the left carotid artery to see if there is enough blood coming out of it. If the blood flow is insufficient, an additional cannula will be inserted into this artery for left hemispheric perfusion. Fortunately, no additional cannula was needed in this study. There was no postoperative PND. The lower incidence of TND in our study than in the earlier study [4] may be explained by the avoidance of circulatory arrest in this study.

Besides arch surgery, cannulation of the innominate artery can also be used in other procedures, such as ascending aorta replacement, which needs open distal anastomosis, semiarch replacement, repeat surgery, or severely calcified ascending aorta [12].

Cannulation of the innominate artery has its limitations. First, the innominate artery must be free of disease. If there is dissection or severe atherosclerotic changes, the innominate artery should not be used. Second, additional time is needed for anastomosis of the graft to the innominate artery, which usually takes about 10 to 15 minutes. Furthermore, bleeding from the suture line and “weeping” through the graft during CPB are inevitable. Usually, these resolve spontaneously after weaning of the CPB and administration of protamine in most patients.

The size of the innominate artery is also important. When the innominate artery is too small, the whole lumen may be occluded after application of the inclusion clamp. In this study, the smallest innominate artery was 9 mm. After application of the inclusion clamp, the mean arterial blood pressure could be maintained above 50 mm Hg in all patients. Therefore, we believe that the side-graft technique is feasible in most patients.

In conclusion, cannulation of innominate artery with a side graft is a safe, fast, and simple technique in arch surgery. It has the advantages associated with axillary artery cannulation but avoids the additional surgical incisions. It also causes less damage to the innominate artery than direct cannulation of innominate artery. Therefore, cannulation of the innominate artery with a side graft is a good option for CPB and HACP in arch procedures.

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INVITED COMMENTARY

Transient or permanent neurologic deficits remain the major cause of morbidity and mortality after complex aortic arch reconstruction. Neuroprotective strategies during aortic arch surgery include hypothermic arrest (HCA) alone, HCA in conjunction with retrograde cerebral perfusion (RCP), or antegrade cerebral perfusion (ACP), moderate hypothermia with ACP, and even normothermic complete arch replacement without circulatory arrest. The ideal method of arterial cannulation and cerebral and systemic protection remain undefined. Several reports document the safety and efficacy of these various approaches.

However, large clinical series and laboratory data have suggested several limitations of RCP in aortic arch surgery. Svensson and colleagues [1] have documented that the brain is incompletely perfused when using RCP. Okita and colleagues [2] found that the prevalence of transient neurologic dysfunction was significantly higher using RCP when compared with ACP. A recent survey of major aortic centers found 50% preferred selective ACP, 38% used a combination of techniques, and 6% used both HCA and RCP [3]. Numerous arterial perfusion techniques have been described that allow ACP during aortic arch surgery. These techniques include selective cannulation of the ostium of the innominate artery (IA) or left carotid artery (or both of these arteries), cannulation of the axillary artery, cannulation of the innominate artery, and construction of an arch first graft.

Huang and colleagues [4] have described a method of innominate artery perfusion using an 8-mm vascular graft in conjunction with the use of HCA for aortic arch surgery. The majority of patients in this series had type A dissections (34 of 46 patients), 4 patients required surgery for type B dissection, and the remainder had aneurysmal disease of the ascending aorta and arch. The operative mortality rate for this complex set of patients was a respectable 6.5%.

Interestingly, there were no reported neurologic complications of either transient or permanent neurologic dysfunction.

Although the methods and techniques used by Huang and colleagues [4] have largely been described elsewhere for ACP during aortic arch surgery, the novel idea of attaching a side-arm graft to the innominate artery is unique. The authors suggest that a side-arm graft is preferential to direct cannulation for the following reasons: less risk of damage to the innominate artery, less requirement for manipulation of a cannula, and less risk of stenosis of the IA after tying down the pursestring sutures after de-cannulation. Perhaps these reasons are based more on surgeon preference, as many centers report excellent results with direct cannulation. Indeed, the main benefit of direct IA perfusion is the rapidity in which it may be accomplished in an urgent or emergent situation, which requires aortic arch reconstruction (ie, dissection surgery). In addition, the use of a side-biting clamp, as the authors describe, may be more traumatic to the IA than direct cannulation. Therefore, a side-arm graft may be an over complicated method for ACP for most patients. The authors did illustrate one example in which a side-arm graft would be necessary (ie, those patients with small IA diameters).

The authors should be commended on their early series of a unique method to supply ACP during complex aortic arch reconstruction. The absence of any neurologic complications is remarkable in this challenging patient population, and the authors' work contributes to the expanding experience of refining aortic arch surgery.

Derek R. Brinster, MD

*Divisions of Cardiothoracic and Vascular Surgery
Virginia Commonwealth University Medical Center
Medical College of Virginia Campus
West Hospital Bldg, 7th Floor, S Wing
1200 E Broad St
PO Box 980068
Richmond VA 23298-0068
e-mail: dbrinster@mcvh-vcu.edu*