Efficacy and safety of the Direct Cannulation of the Innominate Artery (DCIA) in patients undergoing hemi-arch replacement

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KEYWORDS

DCIA, SACP, DHCA, neurological insults and mortality.

ABSTRACT

Background: Maintaining selective antegrade cerebral perfusion (SACP) in cases mandating deep hypothermic circulatory arrest (DHCA) is the key to preventing major neurological insults.
Objective: The goal of this study was to compare the applicability of direct cannulation of the innominate artery (DCIA) to traditional cannulation using femoral artery side graft (FASG) in patients undergoing open arch operations using adequately sized arterial cannulas.
Methods: The hospital records of 108 consecutive patients who underwent open-arch surgeries at Cairo, and Beni-Suef University hospitals from January 2021 to December 2024 were retrospectively collected and analyzed. We compared pre-, intra-, and post-operative data between patients who underwent conventional FASG (58 patients) and those who were operated on using the DCIA (50 patients) technique.
Results: DCIA showed significantly shorter total operation time (253±134 minutes vs. 318±152 minutes), cardiopulmonary bypass (CPB; 180±37 vs. 200±57), aortic cross-clamp (ACC; 114±52 vs. 154±98), and circulatory arrest time (CA; 15.08±5.25 vs. 20.18±10.35), besides a significantly lower lactate level at the end of the operation (4.20 ± 2.28 vs. 7.33±3.71 mmol). Significantly fewer patients in the DCIA group experienced acute kidney injury and permanent neurologic insults after surgery (1 vs. 8 and 2 vs. 11, respectively). Among the same group, the number of patients who experienced prolonged Mechanical Ventilation (MV), prolonged intensive care unit (ICU) stays, and hospital stays was significantly lower (3 vs. 15, 5 vs. 18, and 5 vs. 19, respectively). The FASG group's total number of early fatalities is far higher than the other group's (7 vs. 1). Although not statistically significant, the FASG had a higher incidence of local wound and vascular problems as well as the need for packed red blood cell transfusion.
Conclusion: Direct cannulation of the innominate artery provided a safe and efficient method of maintaining optimum cerebral perfusion in patients mandating DHCA for open arch repair, and it should be considered as a good alternative to avoid the potential risks of the other conventional methods.

INTRODUCTION

Given the intricacy of aortic arch problems, attaining intraoperative safety with acceptable postoperative morbidity and mortality requires good preoperative surgical planning, technical expertise, and collaborative teamwork.

Open arch repair has been the accepted method for treating various aortic arch diseases, including aneurysmal dilatation and/or dissection, since the first successful study was presented by Griepp et al. in the late 1970s[1,2]. However, the central nervous system is inherently at risk due to the mandatory requirement for circulatory arrest and deep hypothermia during the arch replacement, which needs to be carefully handled[3,4].

Traditionally, cardiopulmonary bypass for such cases is established using the FASG technique[5]. Besides the medical neuroprotective methods, many surgical techniques have been suggested to maintain adequate cerebral perfusion throughout the critical period of the CA, including retrograde cerebral perfusion through the superior vena cava[6] and, more safely, selective antegrade cerebral perfusion[7].

In addition to being time-consuming and technically difficult, accessing the axillary artery for SCAP carries the risk of brachial plexus injury[8]. Since Di Eusanio's first recommendation in 2007, aortic surgeons have increasingly used the innominate artery as an arterial entrance for type A acute aortic dissections[9-11]. Its efficacy and safety in preventing cerebral hypoperfusion during circulatory arrest, however, have not been thoroughly investigated.

In this study, we investigated the applicability and safety of the direct innominate artery cannulation as an arterial access for establishing the CPB in cases undergoing open arch repair compared to the conventional FASG method.

PATIENTS AND METHODS

Methods

Study design:

This study included 108 patients who underwent elective hemi-arch replacement at Cairo, and Beni-Suef University hospitals from January 2021 to December 2024. Patients were divided into two groups based on the arterial access for CPB: group A (control or the FASG group; 58 patients) and group B (DCIA group; 50 patients). Data on preoperative variables, operative time, bypass time, aortic clamp time, circulatory arrest times, lactate level at the end of the operation, and postoperative morbidity, such as prolonged mechanical ventilation (MV), intensive care unit (ICU) stay, hospital stay, and early mortality, were collected and analyzed.

Definitions:

- Aortic arch pathologies demanding open arch repair was defined regarding American College of Cardiology (ACC), American Heart Association (AHA), and the Society for Cardiovascular Angiography & Interventions (SCAI) guidelines[12].
- DHCA technique was standardized regarding criteria accurately described by Ziganshin et al. in 2014[13].
- Prolonged MV (> 24 hours), prolonged ICU stay (> 3 days), prolonged hospital stay (> 14 days), and early postoperative mortality (within 30 days postoperatively) were defined regarding guidelines from the Society of Thoracic Surgeons (STS)[14].
- Permanent neurological deficits (PND) were defined as new focal or global postoperative neurological deficits of ischemic or hemorrhagic origin that lasted for at least seven days, including stroke or coma[15,16].
- Local arterial complications included bleeding, arterial injury, groin seromas, peripheral nerve injury and wound infections[17].

Exclusion criteria:

We excluded patients with vascular lesions precluding the innominate artery as a vascular access, infective endocarditis, preoperative cerebrovascular insult, chronic renal dialysis, concomitant other valvular procedures and patients operated on an urgent or emergency basis.

Study endpoints:

- The study's **primary endpoints** were Permanent neurological deficit, AKI demanding hemodialysis, and early mortality.
- **Secondary endpoints** were Prolonged MV time, Prolonged ICU stay, Prolonged Hospital stay, local wound infection and arterial complications and number of units of packed red blood cells transfused.

Ethical approval:

The ethical committee of Beni-Suef University hospitals approved the study protocol, [Ethical Approval Number: FMBSUREC/09022025/Mahmoud]. Every patient signed an informed written consent for acceptance of the operation. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans[18].

Surgical Technique:

Regardless of the arterial cannulation technique used (DIAC or FASG), all patients were operated on via a median sternotomy that extended to the lower neck, and the arch branches were circumferentially encircled with umbilical tape to be snagged when open arch repair began for a bloodless field. Following full heparinization, central venous cannulation through the right atrial appendage was used to establish CPB.

When FASG technique is used, the common femoral trunk (CFT) was exposed in the groin region and bitten using a side-clamp then longitudinally incised and a 10-mm Dacron tube graft was sutured in an end-to-side fashion using a 5–0 prolene suture. The CFT then is connected to the arterial side of the CPB.

Using the DIAC technique, a 4-0 prolene purse string is placed at the base of the innominate artery, through which a 20-22 Fr aortic cannula with a right-angled tip is introduced and directed either towards the innominate artery to initiate the SACP or into the arch to supply the entire body.

After starting CPB, the cross clamp was properly applied, cardioplegia was administrated through a cannula placed in the pathologic part of the ascending aorta, and the patient was gradually cooled down to 28°C. Proximal aortic anastomosis was usually performed throughout the cooling time using continuous 3-0 proline suture.

When the patient reaches the required temperature, DHCA begins, and SCAP was started by guiding the aortic cannula tip to the inside of the innominate artery and snagging the previously wrapped tape. SACP was set to 10 mL/kg/min for optimum cerebral perfusion. Transverse hemiarch anastomosis is performed under circulatory arrest using 3-0 prolene continuous suture in the conventional manner.

At the end of the arch anastomosis, the aortic cannula's tip is redirected towards the newly fashioned arch to restore the CPB's full flow and to start the rewarming process.

- **Intraoperative monitoring:**

Beside the conventional intraoperative monitoring regarding the electrocardiography (ECG), urine output, peripheral oxygenation, core body temperature and frequent arterial blood gases interpretation throughout the operative time, the following parameters were carefully considered;

Keeping the right radial arterial invasive blood pressure readings at 50-60 mm Hg targeting adequate peripheral perfusion.

Continuous monitoring of the cerebral perfusion was accomplished using properly placed electrodes of the Electro-Encephalogram (EEC) that was interpreted by specialized neurologist and with regional cerebral oxygen saturation (rSO_2) in the bilateral frontal lobes using near-infrared spectroscopy (NIRS). Lateral asymmetry in the EEG and/or >50% decrease in cerebral oximetry by near-infrared spectroscopy were considered as indication for bilateral cerebral perfusion.

Aside from the standard intraoperative monitoring of electrocardiography (ECG), urine output, peripheral oxygenation, core body temperature, and frequent arterial blood gas interpretation during the surgical period, the following factors were carefully considered:

Maintaining the radial arterial invasive blood pressure readings at 50-60 mm Hg is crucial for achieving adequate peripheral perfusion.

Continuous monitoring of cerebral perfusion was accomplished using properly placed electroencephalogram (EEG) electrodes that were interpreted by a specialized neurologist, as well as regional cerebral oxygen saturation (rSO2) in the bilateral frontal lobes using near-infrared spectroscopy (NIRS). Lateral asymmetry in the EEG and/or >50% decrease in cerebral oximetry by near-infrared spectroscopy were considered as indications for bilateral cerebral perfusion.

Statistical analysis:

Sampling method: With an alpha error of 5%, a 95% confidence level, and an 80% power sample, the Medcalc. 19 program was used to determine the appropriate sample size population (108 patients) (Equations are provided by Machin et al. [19]).

Data analysis: Continuous data were expressed as mean and standard deviation or median with the interquartile range and categorical data as percentages. All reported P values are two-sided, and P values of ≤ 0.05 were considered statistically significant. All statistical analyses were done with the help of a professional statistician.

RESULTS

[Data presented as mean± SD, mean (interquartile range), or number (%; all percentages are calculated from total number in each group)]

- **Demographic and pre-operative variables; Table 1:**

A total of 108 patients (40 females) were separated into two groups: Group A (the control group of 58 patients who operated using FASG technique) and Group B (which included 50 patients who used DIAC). Our sample's mean age was 53.58 (+12.47) years. There was no significant difference between the groups in terms of demographic and clinical baseline characteristics (p > 0.05).

Table 1: Preoperative parameters.

Preoperative parameter	Group A (58)	Group B (50)	P Value
Age (years)	52.38 ± 15.57	51.78 ± 10.94	P = 0.8200
Female sex (number %)	5 (8.62%)	3 (6%)	P = 0.6058
Body Mass index (BMI; Kg/m^2)	26.7± 6.5	27.20± 5.4	P = 0.6676
Smokers (number %)	37 (63.79%)	36 (72%)	P = 0.3656
Pulmonary disease	20 (34.48%)	22 (44%)	P = 0.3138
Peripheral vascular disease	9 (15.51%)	7 (14%)	P = 0.8264
Uncontrolled D.M (HBA1C > 7 mg/dl)[20](number %)	19 (32.76%)	14 (28%)	P = 0.5941
Poor LVEF (< 50%)	2 (3.45%)	1 (20%)	P = 0.7761
NYHA class 2 3 4	 2 (3.45%) 50 (86.21%) 6 (10.34%)	 3 (6%) 42 (84%) 5 (10%)	 P = 0.5314 P = 0.6112 P = 0.9538

FEV-1; Forced Expiratory Volume in 1 second, HBA1C; Glycated hemoglobin, LVEF; Left Ventricular Ejection Fraction, NYHA class; New York Heart Association class.

- **Intraoperative variables; Table 2:**

The DIAC technique had significantly shorter total operation time (318 ± 152 vs. 253 ± 134), cardiopulmonary bypass (200±57 vs. 180±37), aortic cross-clamp time (154 ± 98 vs. 114±52), and circulatory arrest time (20.18 ± 10.35 vs. 15.08 ± 5.25). Additionally, the same group had a considerably lower lactate level at the end of the procedure (7.33 ± 3.71 vs. 4.20 ± 2.28), which is a sign of adequate peripheral perfusion during the surgery (p > 0.05).

Table 2: Postoperative parameters.

Intra-operative parameter	Group A (58)	Group B (50)	P Value
Operative time (minutes)	318 ± 152	253 ± 134	P = 0.0212
CPB time (minutes)	200± 57	180± 37	P = 0.0360
ACC time (minutes)	154 ± 98	114± 52	P = 0.0110
CA time (minutes)	20.18 ± 10.35	15.08 ± 5.25	P < 0.0001
Lactate level at the end of the operation (mmol/L)	7.33 ± 3.71	4.20 ± 2.28	P < 0.0001

CPB; Cardio-pulmonary bypass, ACC; Aortic Cross Clamp, CA; Circulatory arrest.

- **Post-operative variables; Table 3:**

Primary endpoints:

In terms of our main outcomes, the DIAC group had a statistically significant lower incidence of permanent neurological deficits (8 (8.65%) vs. 1 (2%)), acute kidney injury demanding hemodialysis (11 (18.97%) vs. 2 (4%)), and early mortality (7 (12.07%) vs. 1 (2%)) (P value <0.05).

Secondary endpoints:

Taking into account the secondary outcomes, a significantly higher proportion of patients in the control (FASG) group needed longer mechanical ventilatory support (15 (25.86%) vs. 3 (6%)), intensive care unit (18 (31.03%) vs. 5 (10%)), and hospital stays (19 (32.76%) vs. 5 (10%)) (P value <0.05). Additionally, the group's patients had a greater rate of local vascular complications, wound infections, and the need for PRBC transfusions (packed red blood cells [units]). Nevertheless, the difference was not statistically significant.

Table 3: Postoperative parameters.

Post-operative parameter	Group A (58)	Group B (50)	P Value
Primary Endpoints:			
Permanent Neurological Deficits	8 (8.65%)	1 (2%)	P = 0.0278
AKI demanding Hemodialysis	11 (18.97%)	2 (4%)	P = 0.0177
Early mortality	7 (12.07%)	1 (2%)	P = 0.0805
Secondary Endpoints:			
Prolonged MV time (> 24 hours)	15 (25.86%)	3 (6%)	P = 0.0060
Prolonged ICU stay (> 3 days)	18 (31.03%)	5 (10%)	P = 0.0081
Prolonged Hospital stay (> 14 days)	19 (32.76%)	5 (10%)	P = 0.0047
Wound infection	5 (8.62%)	1 (2%)	P = 0.1360
Local Arterial complication	7 (10.34%)	1 (2%)	P = 0.0805
PRBC's Transfusion Packed red blood cells (units)	3.13 ± 1.84	2.82 ± 1.96	P = 0.3989

AKI; Acute Kidney Injury, MV; Mechanical Ventilation, ICU; Intensive Care Unit, PRBC's; Transfusion Packed red blood cells.

DISCUSSION

Selective antegrade cerebral perfusion is presently the most effective approach to ensure that the brain receives adequate blood flow while undergoing the deep hypothermic circulatory arrest required for open arch repair. Initially, axillary artery cannulation was used as an effective access method. However, it has been shown to be technically challenging and time-consuming, with the risk of limb hypoperfusion, seroma formation, disparate surgical-site bleeding, and local nerve injury and/or compression[21-23].

Because of the larger caliber and ease of accessibility, cannulation of the innominate artery has been suggested as a substitute for the axillary artery. Initially, the most popular method was side grafting; however, a number of studies have examined the feasibility of direct innominate artery cannulation using a pediatric-sized pediatric cannula (14–16 Fr. diameter). Nevertheless, these cannulas are not always available[24-26].

Surgeons routinely use femoral artery cannulation for thoracic aortic surgery, with considerable success. However, in cases of acute type 1 aortic dissection, femoral artery cannulation can result in cerebral hypo-perfusion[27-28].

In this study, we propose to employ a right-angled aortic cannula at the base of the innominate artery. This cannula can be directed toward the brain during DHCA, and it can be re-positioned to perfuse the entire aortic when arch repair is complete.

Regarding preoperative parameters, most of our patients were male (68 (62.96%)) with a mean age of 53.58 (+12.47) years that coincides well with data published by authors dealing with such issue[29-31].

Intraoperatively, we found that the DIAC group had shorter operative times (318 ± 152 vs. 253 ± 134), CPB (200±57 vs. 180±37), ACC (15 + 98 vs. 114±52), and CA (20.18 ± 10.35 vs. 15.08 ± 5.25) compared to the other group. Additionally, the lactate level at the end of the procedure was considerably lower in the same group (7.33 ± 3.71 vs. 4.20 ± 2.28), showing adequate peripheral perfusion during the surgery ($p > 0.05$). Unal et al. and Feier et al. found comparable results in studies published in 2014 and 2023, respectively[32-33].

On discussing the primary endpoints, we found higher permanent neurological sequelae, acute kidney injury demanding hemodialysis, and postoperative mortality among patients operated on using femoral artery side grafting (8.65%, 18.97%, and 12.07%) compared to patients operated on using the direct innominate artery cannulation (2%, 4%, and 2%).

In 2007, Di Eusanio and colleagues achieved aortic arch replacement for 55 patients using innominate artery side grafting and reported 3.6% hospital mortality and 1.8% transient neurologic dysfunction with no stroke nor coma[29]. Similarly, Preventza and colleagues reported 1.5% postoperative early mortality, 7.4% acute kidney injury among and 4.4% stroke among their 66 patients who underwent open arch repair using the same technique in 2013[30].

With the DIAC technique using 22-24 Fr. sized cannulas Ji and colleagues achieved no permanent neurological insults and 2.9% early mortality among their 68 patients who underwent aortic arch replacement mainly for aortic dissection in 2008[31]. Comparably, in 2013, Hokenek AF. performed direct IA cannulation on 54 patients using the same size cannulas and the same technique and reported 1.8%, 9.2%, and 3.7% incidences of stroke, transient cognitive impairment, and hospital death, respectively[34].

In 2004, Fusco and colleagues reported an early mortality rate of 17% and an 8% perioperative stroke rate with femoral cannulation[35], with nearly identical indices among patients operated on using right axillary artery cannulation in a 10-year experience study carried out by Etz et al. in 2008 (17% mortality and 11% stroke)[23].

Comparing our results regarding the secondary endpoints, our results concluded significantly less incidence of prolonged mechanical ventilation, prolonged ICU stay, and prolonged hospital stay (6%, 10%, and 10%) compared to the FASG group’s patients (25.86%, 31.03%, and 32.76%) and statistically insignificant less incidence of local wound infection, arterial injury, and fewer units of PRBCs needed to be transfused among the same group (2%, 2%, and 2.82 ± 1.96 vs. 8.62%, 10.34%, and 3.13 ± 1.84).

In contrast, Feier et al. found shorter ICU and in-hospital stays among DIAC patients compared to FA cannulation patients, but the differences didn’t reach the significance level[33]. Tong et al. reported shorter ICU and hospital stays among patients with FASG compared to those operated on using the axillary artery (p-value > 0.05)[28].

CONCLUSION

To enhance patient safety and reduce postoperative neurological complications associated with circulatory arrest during open arch repair procedures, direct arterial cannulation with an aortic cannula featuring a right-angled tip at the offset of the innominate artery offers a secure, uncostly, and efficient approach for achieving selective antegrade cerebral perfusion, serving as a viable alternative to the traditional femoral artery side grafting technique.

Abbreviations:

DCIA	Direct Cannulation of the Innominate Artery
SACP	Selective Antegrade Cerebral Perfusion
DHCA	Deep Hypothermic Circulatory Arrest
FASG	Femoral Artery Side Grafting
CPB	Cardiopulmonary Bypass
ACC	Aortic Cross Clamp
CA	Circulatory Arrest
MV	Mechanical Ventilation
ICU	Intensive Care Unit

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