Perfusion of brain and viscera using modified retrograde cerebral perfusion for aortic arch surgery

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Abstract

Background: Retrograde cerebral perfusion provides a similar neuroprotective effect as antegrade cerebral perfusion during hypothermic circulatory arrest. Neither of them, however, provides blood flow for the abdominal viscera.

Methods: Here we reported a modified retrograde cerebral perfusion by tethering both superior and inferior vena cava with bands around the cannula and clamping the distal ends of both superior and inferior vena caval drainage tubes. Modified retrograde cerebral perfusion (mRCP) was performed in 8 patients.

Results: During mRCP, retrograde perfusion flow was maintained at 3.8±1.8 mL min⁻¹ kg⁻¹ to keep central venous pressure at 21±2 mm Hg. Removing the cross-clamp of the distal end of the inferior vena caval drainage tube, eliminated blood flow in the liver and kidney, while cerebral blood flow decreased from 21.5 to 16 cm/sec.

Conclusions: It is suggested that this technique may increase cerebral blood flow, and provide a supplementary blood flow for the lower body during circulatory arrest.

Introduction

Hypothermic circulatory arrest (HCA) is necessary to provide a clear surgical field for aortic arch replacement. During circulatory arrest, applying anterograde or retrograde cerebral perfusion (RCP) can attenuate ischemic injury to the brain [1]. However, neither type of perfusion provides blood flow to the lower body. Here we describe a modified retrograde cerebral perfusion (mRCP) technique that may perfuse the brain and abdominal organs during HCA.

Methods

Between 28 February 2021 and 30 June 2021, mRCP was performed in 8 patients (all were men, 64±6 years) suffering from acute type A aortic dissection who were scheduled for hemiarch replacement surgery (HRS). We routinely monitored arterial blood pressure, central venous pressure, bilateral regional cerebral oxygen saturation, and nasopharyngeal and rectal temperature. A standard cardiopulmonary bypass circuit was set up. After the oxygenator, the arterial line was bifurcated into one branch for systemic perfusion, and another branch that was connected to the superior vena caval drainage tube preparing for mRCP during HCA (Fig. 1A).

After sternotomy and systemic heparinization, cardiopulmonary bypass was set up by placing a cannula in the femoral artery, and single cannulae were inserted into the superior and inferior venae cavae. During bypass, the communicating branch between the arterial line and superior vena caval drainage tube was clamped. After achieving moderate hypothermia (nasopharyngeal temperature, 25 °C; rectal temperature, 27 °C), the pump was stopped, and both the superior and inferior venae cavae were tethered with bands
around the cannulae. The branch for systemic perfusion and the distal end of the superior vena caval drainage tube were cross-clamped, but the communicating branch between the arterial line and superior vena caval drainage tube was opened, then the pump was restarted as in RCP. In mRCP, the distal end of the inferior vena caval drainage tube was cross-clamped to prevent blood in the inferior vena cava from flowing into the reservoir (Fig. 1B, Video).

Results

During mRCP, retrograde perfusion flow was maintained at 3.8±1.8 mL min⁻¹ kg⁻¹ to keep central venous pressure at 21±2 mm Hg ((Fig. 2), and $rSO_2$ decreased by less than 10% of baseline. Pressure in the inferior vena cava, which was measured via the side opening of the cannula, increased to 11±3 mmHg. Blood flow in the brain, liver and kidney was observed during mRCP(Fig. 3). Removing the cross-clamp of the distal end of the inferior vena caval drainage tube, eliminated blood flow in the liver and kidney, while cerebral blood flow decreased from 21.5 to 16 cm/sec.

Desaturated blood was observed in the aorta throughout mRCP, a flexible sucker was inserted into the descending aorta to drain blood back into the reservoir. After end-to-end anastomoses between the graft and descending aorta, mRCP was stopped, and the communicating branch between the arterial line and superior vena caval drainage tube was cross-clamped again. Then the clamps on the arterial line as well as distal ends of superior and inferior vena caval drainage tubes were removed, which restarted systemic perfusion from the femoral artery.

The mRCP lasted an average of 24±7 mins, and intubation lasted an average of 15±8 h. All patients recovered uneventfully and none suffered neurological complications, paraplegia, or liver dysfunction. Only one patient had mild acute kidney injury. All were discharged an average of 7.5±1.4 days after surgery.

Discussion

After the widespread use of anterograde or retrograde cerebral perfusion to protect the brain during aortic arch replacement surgery, researchers have focused on how to minimize ischemic injury to the lower body during the operation. We reported that anterograde cerebral perfusion combined with retrograde inferior vena caval perfusion provides continuous blood flow to the brain, abdominal viscera, and spinal cord during HCA [2-4]. However, this technique requires cross-clamping three arterial branches of the aortic arch, which is unnecessary during HRS. Another option is total venous retrograde perfusion [5, 6], which is unsafe for hemiarch surgery because it can lead to severe fluid retention and decreased cerebral oxygen saturation [7].

Here we describe a modification of RCP for total body perfusion. Blood from the upper body enters the lower body via the azygos, hemiazygos and pericardiophrenic veins. Pressure in the inferior vena cava
increased within 1 min if the inferior vena cava was tethered and the end of its drainage tube was cross-clamped. This pressure was maintained at 11 mmHg. Simultaneously, blood flowed into the liver and kidney. These observations suggest that mRCP can effectively perfuse the lower body.

Conventional RCP is thought to provide adequate blood to the brain only if the central venous pressure reaches approximately 31 mmHg, which is higher than the maximal safe limit of 25 mmHg \[^8\]. Our experience is that removing the drainage cross-clamp of the inferior vena caval tube sharply reduces both central venous pressure and cerebral blood flow. This presumably reflects the shunting of cerebral blood flow via communicating branches between the superior and inferior venae cavae. This may explain, at least partly, why conventional RCP cools neurocytes but does not provide them with oxygen. In our modified procedure, rSO\textsubscript{2} remained within the normal range throughout arrest, and no postoperative neurologic complications occurred, even though nasopharyngeal temperature was maintained at 25 °C. These findings suggest that mRCP provides substantial blood flow to the brain.

The mRCP technique differs from total-body retrograde perfusion because the blood level in the reservoir remains stable. None of the eight patients that we treated suffered fluid retention or injury to vital organs, suggesting that mRCP is safe.

**Conclusions**

Our experience with this case series suggests that mRCP provides adequate blood flow to the brain and abdominal organs during HCA as part of HRS. Further studies are needed to test whether the new technique is safe during total aortic arch surgery, and whether it improves surgical outcomes.

**Abbreviations**

HCA Hypothermic circulatory arrest

RCP Retrograde cerebral perfusion

mRCP modified retrograde cerebral perfusion

HRS Hemiarch replacement surgery

**Declarations**

**Ethics approval and consent to participate**

The design of the study, assessment and intervention protocols, as well as informed consents, were reviewed and approved by the Ethics Committee of West China Hospital (No.2018(24))

**Consent for publication**
Approximately 1 day before the surgery, each participant is informed of the study design, general purpose, assessment protocols and interventions. Written informed consent have been collected from all participants.

**Availability of data and material**

The data used and analyzed during the current study are available from the corresponding author.

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**Competing interests**

The authors declare that they have no competing interests.

**Authors’ contributions**

XY, JL and LD were involved in the conception and design of the study, drafted the manuscript, LD supervised the revisions and approved the final manuscript.

XJY and XLL were involved in the study conduction, XLL was involved in data collection, ZCT was involved in video production.

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**References**


**Figures**

**Figure 1**

Schematic of the cardiopulmonary bypass and its connection with the body.

(A) Before and after modified retrograde cerebral perfusion (mRCP), venous blood returns from the (1) superior vena cava and (2) inferior vena cava to the blood reservoir, then it is pumped into the oxygenator and then back to the artery via the (4) arterial tube. Inferior vena cava pressure is monitored via a (5) side opening of cannulation. The communicating branch between the arterial line and superior vena caval drainage tube is clamped. (B) During mRCP, the branch for systemic perfusion and the distal ends of both superior and inferior vena caval drainage tubes are cross-clamped, and the (3) communicating branch between the arterial line and superior vena cava drainage tube is opened. The oxygenated blood is routed as in RCP, while the other part of the blood comes to the lower body via the communicating branch between superior and inferior venae cavae in order to perfuse the vital organs in the lower body.

![Figure 1](image)

**Figure 2**

Blood flow and pressure during mRCP. (A) Blood flow rate. (B) Pressures in the central line and inferior vena cava. CVP, central venous pressure; IVC, inferior vena cava.
Figure 3

Observation of blood flow to the brain and visceral organs during mRCP. (A) Cerebral blood flow was 21.5 cm/sec based on transcranial Doppler ultrasonography during mRCP, and it decreased to 16 cm/sec after the distal end of the inferior vena caval drainage tube was unclamped (red arrow). (B-C) Blood flow was observed in the (B) liver (yellow arrow) and (C) kidney (green arrow) using transesophageal echocardiography.

Supplementary Files

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- Video.mp4