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Central Partial Bypass Management Technique for Distal Arch Surgery

Amanda Cornelius, BS, CCP; Krithika Ramaprabhu, MBBS; Elizabeth Stephens, MD, PhD; Nishant Saran, MD; Alberto Pochettino, MD

Cardiovascular Sugery, Mayo Clinic, Rochester, Minnesota

Abstract: Circulatory arrest and left heart bypass are the most common approaches to manage perfusion during distal arch surgery. We report a novel perfusion technique utilized in the treatment of aneurysmal Komerrell's diverticulum (KD) and aberrant subclavian artery (ASA) that allows for a reliable conduct of perfusion. From 2016 to 2020, 12 adult patients with aneurysmal KD and ASA underwent repair of distal arch through lateral thoracotomy ipsilateral to the arch side using central partial bypass. Once the patients were fully heparinized the lower thoracic aorta and the right atrium were cannulated. The cannulas were connected to the cardiopulmonary bypass (CPB) circuit with an oxygenator. Partial bypass was initiated. Ventilation via anesthesia was continued as the mode of gas exchange to the upper body while the CPB circuit provided gas exchange to the lower body. In all patients, CPB was initiated allowing the patient to maintain a mean arterial pressure >60 mmHg in the femoral artery and a mean arterial pressure (MAP) >80 mmHg in the radial artery to allow adequate native ejection into the proximal circulation. The venous line was partially occluded to control the radial pressure. The aorta was cross clamped proximal and distal to the KD to isolate the aorta to be replaced. KD was excised in all patients having performed contralateral subclavian to carotid transposition previously. Once the aorta was reconstructed, clamps were released and the patients were weaned off CPB. All were extubated on the same day and there was no early mortality. **Keywords:** cardiac, cardiopulmonary bypass, vascular ring, Kommerell diverticulum, aberrant subclavian artery. *J Extra Corpor Technol. 2021;53:306–8*

The presence of a vascular ring (VR) in the adult vs. pediatric population is infrequent. Of those adult patients with a VR, 18% have an aneurysmal Komerrell's diverticulum (KD) and aberrant subclavian artery (ASA) (1). This pathophysiology leads to an increase in dissection (19–55%) and mortality (2–5). Excision of the diverticulum and reconstruction of the descending aorta is necessary. Left heart bypass or cardiopulmonary bypass (CPB) with deep hypothermic circulatory arrest are routinely used in the treatment of these patients. At our institution, we use a CPB circuit in conjunction with native heart function/circulation to the upper body while bypassing the distal arch and maintaining lower body circulation via the CPB circuit. This has been termed central partial cardiopulmonary bypass.

DESCRIPTION

From 2016 to 2020, 12 patients with right aortic arch, aneurysmal KD and left aberrant subclavian artery (ASA) underwent repair of the distal arch using central partial cardiopulmonary bypass (Table 1). This study was approved as "exempt" by the Mayo Clinic Institutional Review Board (IRB #18–003188).

The first stage for VR repair consists of anastomosing the aberrant subclavian artery to the carotid artery. The second stage involves a thoracotomy incision on the same side as the arch, removing the diverticular portion and replacing a segment of the aorta. This repair can be completed without cardiopulmonary bypass (CPB) or with left heart bypass. Concern for the attributes of KD and its aneurysmal tissue requires careful aortic clamp placements and CPB support. If the proximal aorta

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Address correspondence to: Amanda Cornelius, BS, CCP, Staff Perfusionist, Cardiovascular Surgery, Mayo Clinic, Mary Brigh Building, Floor 01, Room 735, 1216 Second Street SW, Rochester, MN 55905. E-mail: cornelius.amanda@mayo.edu
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Table 1. A summary of the clinical characteristics of the patients in this article.

Patient	Age (years)	Gender	Size (body surface area)	Partial Bypass Time (minutes)
1	20	Female	1.6	81
2	21	Female	1.78	67
3	38	Male	1.78	73
4	25	Female	1.97	69
5	43	Female	1.94	81
6	43	Female	1.78	69
7	21	Female	1.74	65
8	62	Male	2.35	72
9	55	Female	1.69	60
10	57	Female	2.12	84
11	73	Female	1.74	74
12	49	Male	2.4	67

cannot be clamped, an open repair under deep hypothermic circulatory arrest is required. When the proximal aorta can be clamped normothermic central partial CPB perfusion strategy is used.

Livanova S5® heart-lung machines (HLM) were used in all central partial bypass procedures with an arterial 1/2-inch internal diameter tubing roller pump (Livanova, London, UK) or Revolution® centrifugal pump (Livanova, London, UK). EPIC® (Verona, WI) electronic health record was connected to the S5 HLM to collect patient and CPB data. Terumo Capiox® FX oxygenator with integrated arterial filter (Terumo Cardiovascular Systems, Ann Arbor, MI) and hard-shell venous reservoir (FX 15–30 or FX25–40) were used. A 3/8″ × 3/8″ arterial-venous (AV) loop was standard. All CPB components (tubing, oxygenator/reservoir) contained biocompatible surface coating X-Coating® (Terumo, Ann Arbor, MI). Cardiotomy suction was returned to the venous reservoir. The cardiopulmonary bypass circuit was primed using 1,215-mL Plasmalyte-A, 10,000 units heparin, and 25-mEq 8.5% sodium bicarbonate.

The patients remained warm at normothermic temperatures using the CardioQuip® heater cooler (CardioQuip LLC, College Station, TX). Heparin loading doses of 350–450 U/kg were used to achieve an activated clotting time >400 seconds, as measured by iSTAT® Celite® Activated Clotting Time (ACT) test (Abbott Point of Care, Princeton, NJ). A one-to-one reversal dose of protamine to heparin was used for reversal of anticoagulation. Autologous priming techniques were occasionally used to reduce hemodilution. Patient pressure monitoring sites include the radial artery contralateral to the arch and femoral artery. In the right-sided arch, the right subclavian is clamped during distal arch reconstruction and the proximal pressure can only be monitored via the left radial artery. To monitor brain oxygenation, bilateral cerebral near-infrared spectroscopy (NIRS) with noninvasive sensors were placed on the forehead using the Nonin® device (Nonin Medical Inc., Plymouth, MN).

Once the patients were fully heparinized and adequate ACT obtained, the descending aorta was cannulated over a wire (Seldinger technique) using an 18 or 20 French OptiSite® arterial cannula (Edwards, Irvine, CA). The perfusionist verifies patency of arterial cannula by confirming the arterial line pressure is consistent with the patient's arterial blood pressure. Additionally, arterial line pulse pressure is observed to reconfirm arterial cannula patency utilizing a manometer, which is routinely used to measure arterial line pressure. Next, the right atrium was cannulated using a Medtronic DLP® (Minneapolis, MN) 24- or 28-French single-stage right angle or straight venous cannulae. The cannula is placed directly into the right atrium when the repair is performed via right thoracotomy.

Cardiopulmonary bypass was slowly initiated allowing the patient to maintain a normal mean arterial pressure and ejection. This is done by partially occluding the venous line to control the amount of volume draining from the patient. The goal is to maintain a mean arterial pressure (MAP) >60 mmHg in the femoral artery and a MAP >80 mmHg in the radial artery. Single lung ventilation and inhaled anesthetics via anesthesia is continued throughout the procedure. The lung continues to function as the mode of gas exchange to the head while the CPB circuit provides oxygenation and CO_2 removal to the lower body. Next, a cross clamp is temporarily applied to isolate the portion of the proximal aorta to be resected. This is often referred to as a "test clamp" as upper body hypertension frequently occurs after the clamp has been applied. This is treated by increasing the drainage into the venous reservoir and/or using short-acting vasodilators with the goal of maintaining a MAP >80 mmHg in the radial artery. Vasodilators are administered via the Swan-Ganz catheter to directly decrease the upper body pressure (as measured/indicated by the radial artery line). This volume and its preload provide the necessary resistance controlling the pressure seen in the radial artery line. Increasing the radial artery pressure requires venous return to be restricted, which increases blood volume to the patient. Vacuum-assisted venous drainage may be used judiciously if venous return is not satisfactory. The femoral artery pressure is controlled by the arterial CPB circuit flow in a direct manner. Increasing the femoral artery pressure necessitates the perfusionist increase the arterial flow and conversely, decreasing the femoral artery pressure requires decreasing the arterial flow. Adequately balancing the patient's pressures typically involves precise manipulation and coordination of the anesthesiologist and perfusionist. After partial CPB has been established successfully, the surgical repair continues.

DISCUSSION

The advantages of using this perfusion strategy of partial central cardiopulmonary bypass are avoidance of the consequences of hypothermia (≤34°C) and circulatory arrest. The CPB circuit supports a heat exchanger, which maintains a normothermic bladder temperature of 37°C during CPB. This technique avoids the need for any hypothermia and circulatory arrest as many would otherwise require during distal arch repair. Hypothermia has been shown to increase risk of neurological complications and decrease platelet and coagulation function requiring allogeneic blood transfusions (6). Circulatory arrest without cerebral perfusion is associated with the highest rate of death or stroke (7). In addition, low-volume aortic arch centers often use circulatory arrest without cerebral perfusion (8). The absence of circulatory arrest allows this technique to be used across more centers. This technique avoids cardiac and distal organ ischemia via cannulation of the lower thoracic aorta and right atrium thus allowing the heart to maintain native gas exchange and circulation of the upper body. The CPB circuit supports lower body perfusion after the distal thoracic aorta is clamped.

Endovascular treatment options for complex anatomic configurations of the aortic arch are also rapidly expanding, with the theoretical advantage of maintaining lower body perfusion in the procedural period. Aortic arch debranching and extraanatomic bypasses with endovascular stenting are an adaptable technique that can be applied to a plethora of arch pathologies (9). However, the incidence of spinal cord ischemia remains significant. Our perfusion strategy ensures safer results with lower incidence of spinal cord ischemia compared to endovascular treatment (10).

The disadvantages of the procedure include the inability to balance flows when the aortic clamp is applied. The inadequate venous return may cause upper body hypertension if not treated with medication or the placement of an appropriately sized cannula.

We have shown this to be a safe and very effective therapy for this select group of patients. The use of this approach decreases the incidence of spinal ischemia, avoids deep hypothermic circulatory arrest and end-organ ischemia in patients with this constellation of congenital abnormalities.

A link to a video describing our procedure: "Repair of Adult Vascular Ring" (https://medprofvideos.mayoclinic.org/videos/the-mayo-clinic-approach-to-repair-of-adult-vascular-ring#.YGTY21GECiU.link).

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