JECT. 2004;36:245–249
The Journal of The American Society of Extra-Corporeal Technology

A Versatile Extracorporeal Circuit for Use During Repair of Descending and Thoracoabdominal Aortic Aneurysms in High-Risk Patients with Cardiac and/or Pulmonary Dysfunction: A Novel Approach to a Significant Perfusion Management Dilemma

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Abstract: The incidence of ischemic complications associated with repair of descending and thoracoabdominal aortic aneurysms has been significantly reduced by the use of distal aortic perfusion with moderate hypothermia, cerebral spinal fluid drainage, and segmental sequential clamping techniques. However, because the maintenance of proximal perfusion, the adequacy of left heart bypass (LHB), and the ability to ventilate patients on only one lung are all dependent on ventricular and pulmonary function, high- risk patients with descending and/or thoracoabdominal aortic aneurysms in the presence of cardiopulmonary insufficiency or instability present a difficult challenge for the surgical team. Traditional closed LHB circuits become nonfunctional in the event of cardiac arrest or refractory arrhythmias that create hemodynamic instability and are unable to provide necessary pulmonary support if the patient fails to ventilate adequately on one lung during thoracotomy. Furthermore, converting a patient from closed LHB to traditional venoarterial cardiopulmonary bypass (CPB) is frequently difficult, especially when the perfusionist works without the benefit of extra personnel to assist during such crises. Consequently, a modified extracorporeal circuit was designed to provide closed LHB with desired therapeutic adjuncts while also satisfying the additional need for a rapid infusion device, a source of supplemental ventilation/oxygenation, and, if necessary, the ability to convert the patient to venoarterial CPB conveniently in the event of cardiac and/or pulmonary failure during surgery to repair descending and/or thoracoabdominal aortic aneurysms. **Keywords:** thoracoabdominal aneurysm, left heart bypass, ischemic. *JECT. 2004;36:245–249*

Depending on the anatomy of the lesion and the aortic cross clamp time, successful outcomes following surgical repair of thoracic and thoracoabdominal aneurysms can be significantly limited by ischemic events leading to paraplegia, renal failure, and death. However, the literature is replete with information related to the efficacy of closed left heart bypass (LHB) for distal aortic perfusion, cerebral spinal fluid (CSF) drainage, pharmacologic interventions, and moderate hypothermia to avert or minimize ischemic sequelae during surgical repair of descending aortic aneurysms (1–11)

In this regard, LHB provides proximal afterload reduction, distal perfusion, and temperature regulation via a heat exchanger placed in the closed extracorporeal circuit (ECC). A traditional closed LHB circuit consists of inflow into a centrifugal pump and an outflow line through a heat exchanger. However, traditional closed LHB depends on adequate ventricular function to provide sufficient preload to the left atrium or proximal aorta (depending on the cannulation site) to facilitate inflow to the circuit while the heart continues to provide proximal perfusion. In addition, traditional closed LHB circuits do not contain an oxygenator, making the patient totally dependent on single lung ventilation during thoracotomy.

We have been presented with a series of patients requiring either elective or emergent descending aortic aneurysm repair in which our previous technique of traditional LHB with moderate hypothermia, CSF drainage, and segmental repair were desired, but also had to contend with one or more additional complications related to poor ventricular function, refractory arrhythmias, and acute or chronic pulmonary insufficiency, all of which potentially threaten the ability to perform traditional closed LHB effectively. Consequently, we designed a versatile

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circuit that facilitates closed LHB with the additional capabilities of supplemental ventilatory support, temperature regulation, rapid translocation of volume, and is conveniently converted to full venoarterial cardiopulmonary bypass (CPB) in the event of hemodynamic collapse.

SURGICAL/ANESTHETIC TECHNIQUE

General anesthesia consists of fentanyl, diazepam, and pancuronium. A double-lumen endotracheal tube is used for single lung ventilation during the procedure. Arterial catheters are placed in the right radial and femoral arteries to monitor proximal and distal pressures, respectively. A pulmonary artery catheter is placed for additional hemodynamic monitoring. Nasopharyngeal and bladder probes are used for temperature monitoring. A drain is inserted between the third and forth lumbar interspace to facilitate CSF drainage and pressure monitoring. Cerebrospinal fluid pressure is maintained <10 mmHg during the procedures.

After surgical exposure via a left posterolateral thoracotomy incision (with or without concomitant abdominal exposure) and appropriate mobilization of the vascular anatomy, the patient is heparinized (200 IU/kg per surgeon discretion), and the left atrium and left femoral artery are cannulated in preparation for LHB. The left atrium is cannulated via a pulmonary vein with an 18 Fr × 24 Fr two-stage venous cannula (Edwards Life Sciences, Irvine, CA), while the left femoral artery is cannulated with an 18 Fr arterial cannula (Edwards Life Sciences, Irvine, CA).

PERFUSION TECHNIQUE

The ECC is essentially the traditional system used for standard CPB procedures in which all components and tubing are coated (X-coating, Terumo Cardiovascular, Braintree, MA). The ECC consists of an integrated hollow fiber membrane oxygenator (Capiox SX 25 or SX 10, Terumo Cardiovascular, Braintree, MA), centrifugal pump (Terumo Cardiovascular, Braintree, MA), arterial line filter (Terumo Cardiovascular, Braintree, MA), and 3/8-in tubing. The ECC is modified by adding a bridge between what would normally be the venous line in a traditional venoarterial ECC and the centrifugal pump inflow line (Figure 1).

Appropriate placement of tubing clamps effectively configures the ECC to function as a closed LHB circuit by excluding the venous reservoir (Figure 2). However, unlike traditional LHB circuits, this modified LHB circuit incorporates a membrane oxygenator with an integrated venous reservoir and heat exchanger. An arterial line filter is present, although it is bypassed while in the closed circuit configuration. The sampling manifold from the oxygenator is used for arterial blood sampling and as a source of blood flow for in-line arterial blood gas monitoring (CDI-500, Terumo Cardiovascular, Braintree, MA). In-line monitoring is accommodated by incorporating a leured 3/8 × 3/8 × 3/8-inch Y-connector into the bridge (Figure 1). Thus, the sampling manifold serves as an arterial–arterial shunt in which the in-line sensor is incorporated, facilitating real-time arterial blood gas monitoring while in the closed LHB configuration.

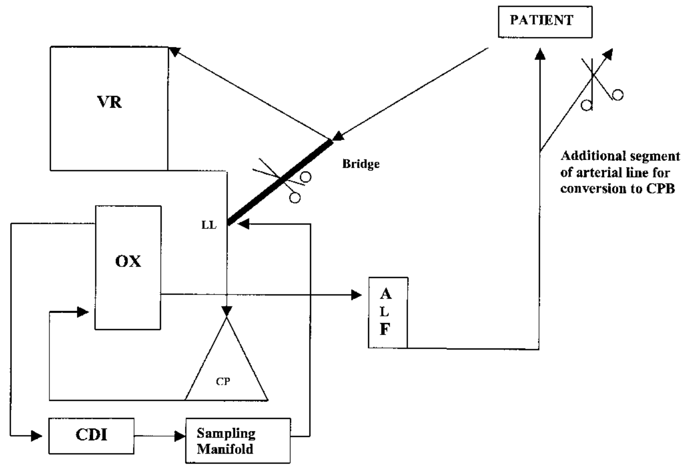

Figure 1. ECC configuration for venoarterial CPB with incorporated bridge (note clamp on bridge). ALF, arterial line filter; CDI, CDI 500 in-line blood gas sensor; CP, centrifugal pump; LL, leur lock 3/8 in × 3/8 in × 3/8 in Y-connector; OX, membrane oxygenator; VR, venous reservoir.

The ECC is primed in the usual manner with approximately 1500 cc of lactated Ringer's solution. When excluding the venous reservoir in the closed circuit configuration (Figure 2), the priming volume of the LHB circuit is 600

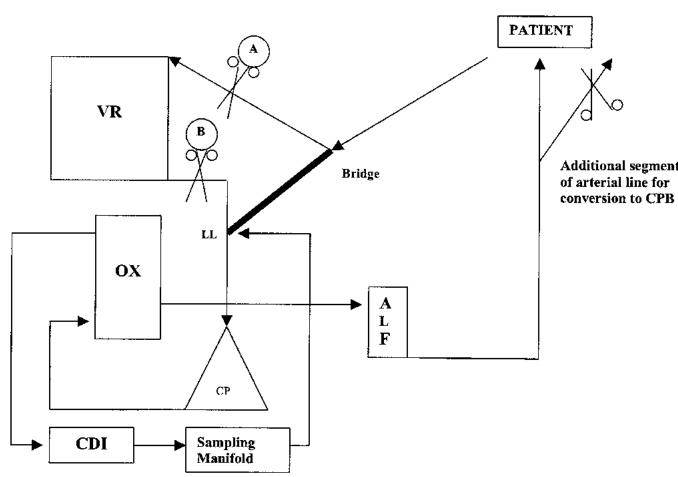

Figure 2. Closed circuit LHB configuration with bridge open and venous reservoir inlet and outlet clamped (note clamps A and B). Rapid volume infusion is performed by briefly opening clamp B, allowing the desired volume to enter the LHB circuit. ALF, arterial line filter; CDI, CDI 500 in-line blood gas sensor; CP, centrifugal pump; LL, leur lock 3/8 in × 3/8 in × 3/8 in Y-connector; OX, membrane oxygenator; VR, venous reservoir.

cc. Because the circuit is intended to be used predominantly in its closed LHB configuration, all lines, including the sampling manifold system, are thoroughly debubbled before initiating LHB.

After heparinization (200 IU/kg per surgeon discretion) to achieve a target activated clotting time (ACT) of 300–350 sec and cannulation, LHB is initiated, adjusting flows to maintain proximal and distal mean blood pressures of 60–90 mmHg during the procedure. Flow rates ranged from 2–4 L/min, depending on hemodynamics and the stage of the procedure. To minimize ischemic time during the procedure, the proximal end of the graft is sutured first, followed by distal movement of the aortic clamp(s) in a segmental sequential fashion, allowing perfusion of the viscera, kidneys, and spinal cord via the heart or LHB circuit, depending on clamp(s) location. Typically, LHB flows are reduced as the cross clamps move distally, allowing the heart to perfuse more of the distal aorta.

Nasopharyngeal temperature is allowed to drift to a minimum of 32–33°C unless the cardiac rhythm becomes erratic. If refractory arrhythmias or some variant of cardiac failure compromises the ability to maintain LHB, venous cannulation, and appropriate modification of existing arterial cannulation will facilitate venoarterial cardiopulmonary support. The distal arterial inflow line is, therefore, configured with a Yd segment to facilitate the additional need for proximal perfusion if complete CPB becomes necessary (Figures 1,2). While the requisite venous and arterial cannulation modifications occur, appropriate manipulation of tubing clamps allows the perfusionist to convert the closed LHB circuit to a traditional venoarterial CPB circuit quickly and effectively, making this potentially challenging alteration of circulatory support strategy rudimentary (Figures 1,2).

Alternatively, if the ability to ventilate the patient on only one lung becomes problematic to any degree during LHB, the perfusionist can effectively supplement oxygenation/ventilation via the hollow fiber membrane oxygenator. In this scenario, the presence of an in-line arterial blood gas monitor makes coordination and precision of ventilation between the anesthesiologist and perfusionist very simple during closed LHB.

The LHB circuit can also be effectively used as either a rapid infusion device or as a means to remove excess volume. Volume can be infused into the LHB circuit from the venous reservoir by opening the appropriate clamp, allowing the desired volume to be drawn into the circuit (Figure 2). Conversely, volume can be removed from the patient by directing blood into the venous reservoir from one of several purge lines that are kept closed during LHB. The choice of volume replacement, removal, or vasoconstriction depends on the magnitude and trend of filling pressures and/or flow rates. The ability to translocate volume rapidly to and from the patient during periods of hemorrhage and/or sequential aortic cross clamp movement makes maintenance of stable hemodynamics very convenient.

As the procedure nears completion, the patient is rewarmed via the integrated heat exchanger within the oxygenator and LHB terminated according to protocol.

To date, we have used our system on 10 patients presenting with acute traumatic transections, chronic aneurysms, or acute ruptured dissections of the descending and/or thoracoabdominal aorta. Each of these patients also presented with some form of cardiac and/or pulmonary dysfunction, making this versatile ECC a superior choice over the limited traditional closed, LHB circuit. There have been no ischemic complications, and all patients were discharged home within 14 days and continue to do well in follow-up.

DISCUSSION

The incidence of spinal cord ischemia and paraplegia during surgical repair of descending aortic aneurysms has been reported to range from 11–25%, depending on surgical technique, aortic cross clamp time, and the extent and location of the lesion (2). The use of LHB in association with moderate hypothermia, CSF drainage, and pharmacologic strategies has decreased the incidence of ischemic complications following repair of descending and/or thoracoabdominal aneurysms (3–11). However, the efficacy of LHB can be compromised by the presence of cardiac and/or pulmonary instability or failure, as well as during periods of hypovolemia caused by massive hemorrhage during the procedure. Of further concern is the difficulty with safely and conveniently converting a patient from traditional LHB to conventional venoarterial CPB when faced with cardiac and/or pulmonary failure, or when the anatomy of the lesion is identified as not amenable to repair during continued LHB. In the absence of qualified assistance, the conversion to conventional venoarterial CPB can be particularly demanding for the perfusionist.

Our versatile ECC was designed to give the perfusionist the ability to respond safely and efficiently to the many potentially demanding perfusion contingencies that may arise during complex repairs of the descending aorta. In addition to well-established techniques of CSF drainage, segmental repair, and moderate hypothermia combined with LHB, our closed circuit configuration facilitates the further ability to translocate volume rapidly to or from the patient, provides real-time arterial blood gas analysis via in-line monitoring, can supplement single lung ventilation, and is easily converted to conventional venoarterial CPB.

Although the inclusion of a membrane oxygenator with an integrated venous reservoir and heat exchanger may be considered unorthodox during LHB, its presence is seminal to the versatility of this ECC. The presence of the venous reservoir, although it is effectively excluded in the LHB configuration, serves as a convenient means of volume management, which is typically not possible with traditional closed LHB circuits. In the event of massive hemorrhage, peripheral catheters may not infuse volume fast enough to maintain adequate hemodynamics. However, using the venous reservoir as a rapid infusion device is fast and convenient, much like the crystalloid bags on portable cardiopulmonary support systems (Figure 2). All patients in our series benefitted from the ability to infuse volume during LHB rapidly, especially during times of significant hemorrhage or when dramatic aberrations of hemodynamics occur while the aortic cross clamp(s) is/are relocated to various sections of the aorta. Although volume can be removed from the patient by directing blood into the venous reservoir during LHB, this has not been necessary in our series of patients.

Although the biocompatible coating on our choice of extracorporeal circuitry is not specifically designed or marketed for low heparin applications, it does demonstrate some innate thromboresistant characteristics (12). Furthermore, many patients with thoracic aortic aneurysms present for repair in a hypocoagulable state because of hemorrhagic shock, consumption of clotting factors at injury sites, or volume resuscitation (13). Per surgeon discretion, we have successfully used a reduced heparin protocol when using this versatile ECC and have never seen visual evidence of clot formation within the system or experienced post-operative bleeding complications. Because there is no blood flowing through the cardiotomy/venous reservoir while in the closed LHB configuration, there is no blood contact with these surfaces. However, if either translocation of blood from the patient into the reservoir during LHB or if conversion to full venoarterial CPB became necessary, we would administer additional heparin to raise the ACT over 480 seconds.

The use of in-line blood gas monitoring has proved to be valuable because it detects impending acid/base and ventilation/oxygenation abnormalities faster than the exclusive use of pulse oximetry with random arterial blood gas sampling by anesthesia personnel during traditional LHB. In this regard, all of our patients benefited from intermittent, supplemental ventilation and/or oxygenation from the LHB circuit to maintain optimal blood gas parameters. Of note, two patients began experiencing troublesome arrhythmias directly related to carbon dioxide retention secondary to the inability to provide adequate single lung ventilation. With supplemental ventilation from the membrane oxygenator, the acid/base status was quickly normalized, and the arrhythmias were resolved. Use of an oxygenator plays a critical role in maintaining hemodynamic stability, especially during one-lung ventilation when significant lung injury/dysfunction exists (e.g., pulmonary contusion, aspiration, chronic obstructive pulmonary disease) (13). None of our patients required conversion from LHB to conventional venoarterial CPB, although simple manipulation of several clamps during cannulation modification would easily facilitate this transition.

This versatile circuit was designed to provide the patient with optimal hemodynamic support by giving the perfusionist convenient control over many of the most common clinical challenges during LHB procedures. Many clinicians must manage these challenging cases without the benefit of extra perfusion personnel, making this versatile circuit very practical. Furthermore, with the exception of an extra segment of 3/8-inch tubing and leured y-connectors, there is no requirement for a custom tubing pack or ancillary components that frequently become cost prohibitive, especially when these types of cases are rarely seen in smaller practices. This versatile system requires minimal, if any, change in established routines by the surgical staff in the operating suite, and is easily configured by modifying nearly any traditional ECC.

Given the presence of all the components of a traditional CPB circuit in our versatile LHB system, we could debate the advantage of its use versus implementing complete venoarterial CPB during complex repairs of the descending aorta. In the closed LHB configuration, our circuit effectively avoids the venous reservoir and integrated cardiotomy with all the requisite defoaming/filter materials and also eliminates a blood–air interface. In addition, our LHB configuration exposes the patient to less than half of the priming volume compared to complete CPB (600 cc vs. 1500 cc). Thus, our versatile system only exposes blood to the ECC tubing and a polypropylene membrane bundle with integrated stainless steel heat exchanger, all of which are coated with a biocompatible polymer. Because these components enable the perfusionist to provide essential modalities and safety features that minimize ischemic complications, our surgical team believes the benefits they provide outweigh any potential morbidity presumably related to additional foreign surface exposure. Institutions that routinely use or have access to heparin-coated extracorporeal circuitry would clearly have the optimal design of this versatile ECC by eliminating any concerns related to a reduced anticoagulation protocol and by being capable of successfully utilizing this ECC without systemic heparinization.

Although traditional LHB circuits have been successfully used during surgery on the descending aorta, the perfusionist is limited when confronted with cardiopulmonary or hemodynamic abnormalities while providing this modality. We believe our versatile ECC provides the perfusionist with the necessary armamentarium to manage these complex cases effectively and conveniently and enhances the probability of favorable outcomes when faced with a variety of clinical challenges and patient presentations in which therapeutic options have been limited during traditional LHB procedures.

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