Minimally Invasive Cardiac Surgery: Implications for the Perfusionist

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Introduction

Until recent years it was uncommon to hear the words minimally invasive surgery and cardiopulmonary bypass (CPB) used in the same sentence. Patient demand has driven the advancement of CPB circuitry, cannula, and techniques to allow for minimally or less invasive cardiac surgery. These procedures are now commonly performed around the world with acceptable outcomes.1-3 A myriad of surgical and perfusion techniques for minimally invasive cardiac surgery have been reported.4-6 It is incumbent upon the clinical team to have a foundational understanding of these strategies in order to appropriately care for each individual patient. What follows is an overview of perfusion strategies for minimally invasive cardiac surgery including circuit and cannula selection as well as management techniques.

CPB Circuit Considerations

Many studies on CPB circuit size in non-minimally invasive procedures can be applied to strategies for minimally invasive cases. Reduction of the CPB circuit surface area and prime volume has been recommended to minimize the incidence of low HCT on CPB and subsequent allogeneic blood transfusions.7,8 Several studies have illustrated that a reduction in surface area–priming volume of the CPB circuit reduces the frequency of low HCT values and subsequently reduces the incidence of allogeneic blood transfusions.9-11 In addition, the use of a biocompatible surface coating has been shown to decrease the incidence of the systemic inflammatory response (SIRS) and reduce platelet dysfunction.12-15 Efforts to reduce circuit surface area and prime volume in minimally invasive adult procedures may include reduction of venous line size from ½” to 3/8”, circuit line shortening, and selection of lower prime oxygenators and arterial filters.

Minimally invasive cardiac procedures often use smaller caliber venous cannulas that have a higher resistance and render gravity venous drainage insufficient to allow for adequate CPB flow. For this reason augmentation of venous drainage is often required in order to achieve adequate CPB flow. Augmentation of venous flow can be achieved by utilizing either vacuum assisted venous drainage (VAVD) or centrifugal assisted venous drainage (CAVD).

VAVD is relatively simple and has been used in clinical practice for approximately ten years now.16 VAVD techniques can be performed safely but have inherent risks that clinical teams must be familiar with. VAVD is performed via the application of external negative pressure with a vacuum regulator (lowest negative pressure -100mmHg) to a non-vented hardshell venous reservoir. This negative pressure is ultimately imparted on
the venous system of the patient and increases venous blood flow. The closed nature of
the VAVD system creates the opportunity for positive pressurization and paradoxical
venous air embolism.\textsuperscript{17} For this reason, it is recommended to monitor positive pressure
and use a reservoir with a positive pressure relief valve. If a centrifugal arterial pump is
used in the CPB circuit there is a risk of air entrainment via the hollow-fiber membrane
oxygenator.\textsuperscript{18} This risk can be minimized by incorporating a one-way flow valve in the
tubing between the venous reservoir and the oxygenator. In addition, studies have shown
that air entrained through the venous line of the CPB circuit can be detected in the arterial
line.\textsuperscript{19} In the setting of venous air entrainment, vacuum assist has been shown to
increase the total number of emboli detected in the arterial line and should be avoided.\textsuperscript{20}

CAVD is another method of augmenting venous drainage that may be considered more
complicated than VAVD since it requires the perfusionist to operate two centrifugal
pumps simultaneously. CAVD utilizes a second centrifugal pump that is placed in the
venous line of the CPB circuit. The centrifugal pump creates negative pressure at the
inlet and actively pumps venous flow. As with VAVD, CAVD in the setting of venous
air entrainment has been shown to increase the volume of emboli, however it has been
suggested that CAVD breaks the emboli into smaller emboli and allows for easier
passage through the CPB circuit.\textsuperscript{21} The advantages of CAVD include the absence of the
risks inherent to VAVD, reservoir pressurization and oxygenator air entrainment.
CAVD also provides the option to use a soft shell venous reservoir that has been shown
in some studies to reduce blood activation and improve patient outcome.\textsuperscript{22,23}

**Arterial Cannulation Considerations**

The surgical procedure and strategy will dictate the arterial cannulation technique
required. The options for cannulation site include ascending aorta, femoral artery, and
axillary artery. The ascending aorta is commonly used for procedures that include an
upper or lower hemi-sternotomy, e.g. aortic or mitral valve procedures. The femoral
artery is often used for procedures that utilize a right thoracotomy incision, e.g. mitral
valve, atrial septal defect (ASD), or tricuspid valve repair (TVR) procedures. The
axillary artery has been used for minimal access ascending and aortic arch surgery
through an upper hemi-sternotomy.\textsuperscript{24}

There are arterial cannulas that have been designed primarily for minimally invasive
cardiac valve surgery. CardioVations (Edwards Lifesciences; Irvine CA) is a system of
minimally invasive cannulas that were designed to facilitate the Port-Access\textsuperscript{®} procedure.
Port-Access\textsuperscript{®} commonly utilizes the EndoArterial Return\textsuperscript{®} femoral artery cannula that is
inserted under direct vision using the seldinger technique. For isolated mitral valve
procedures the EndoClamp can also be used to facilitate endovascular aortic cross
clamping, cardioplegia delivery, and aortic root venting. The EndoClamp is inserted
through a side arm of the EndoArterial Return\textsuperscript{®} cannula and advanced into the ascending
aorta under transesophageal echocardiogram (TEE) guidance.
The Remote Access Perfusion (RAP™) arterial cannula (Estech; San Ramon, CA) has been designed for femoral artery cannulation under direct vision using the seldinger technique. This cannula is advanced into the ascending aorta under TEE guidance. The RAP™ cannula comes with or without a balloon to facilitate endovascular aortic cross clamping, cardioplegia delivery, and aortic root venting.

The ascending aorta can be cannulated for minimally invasive procedures with a variety of cannulas that have been designed for ascending aortic cannulation. At our center we use a small caliber (7Fr) wire-reinforced diffusion cannula. There are other arterial cannulas such as the Fem-Flex II™ (Edwards Lifesciences; Irvine, CA) and Bio-Medicus® (Medtronic; Minneapolis, MN) cannulas that are designed for percutaneous femoral arterial cannulation using a modified seldinger technique. The axillary artery can be cannulated utilizing the graft interposition technique and sewing a 8mm Gore-Tex® graft end-to-side to the artery and then inserting a 8mm wire-reinforced cannula into the graft.

**Venous Cannulation Considerations**

The surgical procedure and strategy will also dictate the venous cannulation technique required. If an upper or lower hemi-sternotomy is performed then direct right atrial (RA), superior vena cava (SVC), or inferior vena cava (IVC) cannulation can be utilized. If a right thoracotomy is performed then the right femoral vein is commonly cannulated and placement is guided via TEE. The femoral venous cannula can be advanced through the RA and into the SVC for bi-caval single cannula drainage or can be placed at the junction of the IVC and RA for bi-caval dual cannula drainage. SVC cannulation can also be performed percutaneously using a modified Seldinger technique through the internal jugular (IJ) vein.

Cardiovations (Edwards Lifesciences; Irvine CA) produces femoral venous cannulas that were designed to facilitate the Port-Access® procedure but can be used for other minimally invasive procedures as well. These cannulas are commonly inserted in the femoral vein under direct vision using the Seldinger technique. They are also long enough (65cm) to be advanced into the SVC to facilitate bi-caval single cannula drainage.

There are several other femoral venous cannulas that have been designed to facilitate peripheral CPB and can be used for minimally invasive cardiac surgery. Fem-Flex II™, Bio-Medicus®, and RAP femoral venous cannulas are manufactured in a variety of sizes. Depending on the size of the cannula, they can be placed percutaneously or under direct vision. It is common practice at our center to perform all femoral cannulation under direct vision.

Minimally invasive procedures of the right heart (e.g. ASD or TVR) require SVC drainage and the IJ can be cannulated. A Bio-Medicus® 15Fr or 17Fr arterial cannula can be placed percutaneously and advanced under TEE guidance to the RA/SVC junction. This bi-caval technique requires the perfusionist to split the venous line to facilitate IVC and SVC drainage.
**Cardioplegia Considerations**

The EndoClamp catheter can be utilized to facilitate endovascular aortic cross clamping, antegrade cardioplegia delivery, aortic root venting, and aortic root pressure monitoring during mitral valve or right heart procedures. The EndoClamp is advanced through the EndoArterial Return® cannula, up the descending aorta, and into the ascending aorta under TEE guidance. The EndoClamp incorporates a balloon that is inflated with saline via a separate lumen to occlude the aorta. Once the balloon is occlusive, antegrade cardioplegia is delivered through a separate lumen to arrest the heart. Strict attention must be given to the aortic root pressure, balloon pressure, right radial pressure, and TEE to confirm appropriate placement of the balloon and effective cardioplegia delivery.

The EndoPlege sinus catheter and EndoVent pulmonary artery (PA) catheter are also available from Cardiovations to facilitate retrograde cardioplegia delivery and PA venting. These cannulas are also part of the Port-Access® procedure and are inserted percutaneously via the IJ.

The RAP™ cannula is utilized in a similar fashion to the EndoArterial Return® with EndoClamp. The difference is the RAP™ cannula incorporates the endovascular aortic cross clamping, antegrade cardioplegia delivery, aortic root venting, and aortic root pressure monitoring into one cannula.

The most common strategy for cardioplegia delivery in minimally invasive procedures is via direct cannulation of the aorta with a 14Fr or 16Fr cardioplegia needle. The needle also allows aortic root venting to be performed. Retrograde cardioplegia catheters can also be directly inserted. At our center, we prefer not to use retrograde cardioplegia because it is difficult to assess the position of the catheter as well as confirm the adequacy of delivery. Further, a coronary sinus injury would be a significant complication in the minimally invasive setting.

**Conclusion**

Minimally invasive cardiac surgery is performed commonly with acceptable outcomes. With a thorough understanding of the foundational concepts of these procedures they can be performed safely and effectively. Each individual patient requires surgical, anesthetic, and perfusion collaboration to identify the optimal strategy for that patient’s operation.

**References**


