OFF-PUMP CORONARY ARTERY BYPASS SURGERY
A GUIDE TO MANAGING THE HEMODYNAMIC CHANGES DURING OPCAB AND MICS-CABG

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Dr. Sadel practiced cardiac anesthesia for 25 years. He completed one year of general surgery and three years of anesthesia residency at Temple University Hospital, Philadelphia, PA. He developed a passion for working in the cardiac operating room and completed a fellowship in cardiothoracic anesthesia at Emory University Hospital, Atlanta, Georgia and stayed there as an Assistant Professor of Anesthesia for the next eight years.

During the early part of his time at Emory, he worked with a cardiac surgeon who began performing a new procedure that was to become OPCAB (off-pump coronary artery bypass) surgery. Dr. Sadel had the opportunity to provide anesthesia for many of these early cases and was involved in the learning curve that eventually resulted in OPCAB becoming a routine procedure.

In 2000, he went to Staten Island University Hospital, Staten Island, New York to help start a new cardiac surgery program. The Chief of Cardiac Surgery was an off-pump surgeon and the new program evolved to become an almost exclusively off-pump center for CABG (coronary artery bypass graft) surgery. In 2005, the surgeon decided to try performing CABG surgeries via a minimally invasive cardiac surgery (MICS) – thoracotomy approach. The new procedure started as the MVST (multi-vessel small thoracotomy) and evolved to what is the MICS-CABG today. Dr. Sadel provided the anesthesia for most of the cases, was heavily involved in developing the techniques for the management of the hemodynamic changes in these cases, and was instrumental in helping to make MICS-CABG a viable procedure. MICS-CABG eventually became a routine procedure at Staten Island University Hospital.

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2.0</td>
<td>PART 1: OFF-PUMP CORONARY ARTERY BYPASS SURGERY (OPCAB)</td>
<td>2</td>
</tr>
<tr>
<td>3.0</td>
<td>OVERVIEW OF THE SURGICAL PROCEDURE</td>
<td>3</td>
</tr>
<tr>
<td>3.1</td>
<td>LAD</td>
<td>3</td>
</tr>
<tr>
<td>3.2</td>
<td>PDA</td>
<td>4</td>
</tr>
<tr>
<td>3.3</td>
<td>RCA</td>
<td>4</td>
</tr>
<tr>
<td>3.4</td>
<td>CIRCUMFLEX</td>
<td>4</td>
</tr>
<tr>
<td>3.5</td>
<td>PROXIMAL ANASTOMOSES</td>
<td>5</td>
</tr>
<tr>
<td>4.0</td>
<td>ANESTHESIA SET-UP</td>
<td>5</td>
</tr>
<tr>
<td>4.1</td>
<td>MONITORING</td>
<td>5</td>
</tr>
<tr>
<td>4.2</td>
<td>MEDICATION SET-UP</td>
<td>5</td>
</tr>
<tr>
<td>5.0</td>
<td>ANESTHESIA ISSUES</td>
<td>6</td>
</tr>
<tr>
<td>5.1</td>
<td>PRE-LOAD</td>
<td>6</td>
</tr>
<tr>
<td>5.2</td>
<td>ARRHYTHMIAS</td>
<td>7</td>
</tr>
<tr>
<td>5.3</td>
<td>TREATING ISCHEMIA</td>
<td>8</td>
</tr>
<tr>
<td>6.0</td>
<td>AVOID THE ISCHEMIC SPIRAL</td>
<td>8</td>
</tr>
<tr>
<td>6.1</td>
<td>FIRST RESPONSE TO ISCHEMIA</td>
<td>8</td>
</tr>
<tr>
<td>6.2</td>
<td>TIPS TO IMPROVE BP</td>
<td>8</td>
</tr>
<tr>
<td>6.3</td>
<td>SURGICAL CONSIDERATIONS FOR MANAGING ISCHEMIA</td>
<td>8</td>
</tr>
<tr>
<td>6.4</td>
<td>STARTING WITH A SEVERELY IMPAIRED HEART</td>
<td>9</td>
</tr>
<tr>
<td>6.5</td>
<td>POST ANASTOMOSIS LV DYSFUNCTION</td>
<td>10</td>
</tr>
<tr>
<td>7.0</td>
<td>SIGNIFICANT MITRAL REGURGITATION</td>
<td>10</td>
</tr>
<tr>
<td>8.0</td>
<td>PUMP-ASSISTED BEATING HEART CABG</td>
<td>11</td>
</tr>
<tr>
<td>9.0</td>
<td>TEMPERATURE</td>
<td>12</td>
</tr>
<tr>
<td>10.0</td>
<td>ANTICOAGULATION</td>
<td>12</td>
</tr>
<tr>
<td>11.0</td>
<td>OPCAB REQUIREMENTS</td>
<td>12</td>
</tr>
<tr>
<td>12.0</td>
<td>PART 2: MINIMALLY INVASIVE CARDIAC SURGERY - CORONARY ARTERY BYPASS (MICS-CABG)</td>
<td>13</td>
</tr>
<tr>
<td>12.1</td>
<td>INTRODUCTION</td>
<td>13</td>
</tr>
<tr>
<td>12.2</td>
<td>ADVANTAGES</td>
<td>13</td>
</tr>
<tr>
<td>13.0</td>
<td>ONE-LUNG VENTILATION</td>
<td>13</td>
</tr>
<tr>
<td>13.1</td>
<td>TIPS FOR USING THE UNIBLOCKER®*</td>
<td>14</td>
</tr>
<tr>
<td>13.2</td>
<td>STEPS TO INCREASE O₂ SATURATION</td>
<td>14</td>
</tr>
<tr>
<td>14.0</td>
<td>PATIENT POSITIONING</td>
<td>16</td>
</tr>
<tr>
<td>15.0</td>
<td>DEFIBRILLATOR PADS</td>
<td>16</td>
</tr>
<tr>
<td>16.0</td>
<td>TEMPERATURE CONTROL</td>
<td>17</td>
</tr>
<tr>
<td>17.0</td>
<td>STEPS OF THE PROCEDURE</td>
<td>17</td>
</tr>
<tr>
<td>18.0</td>
<td>ANESTHESIA SET-UP</td>
<td>19</td>
</tr>
<tr>
<td>19.0</td>
<td>ANESTHESIA ISSUES</td>
<td>19</td>
</tr>
<tr>
<td>20.0</td>
<td>CANNULATION FOR PUMP-ASSIST</td>
<td>22</td>
</tr>
<tr>
<td>21.0</td>
<td>PAIN CONTROL</td>
<td>23</td>
</tr>
<tr>
<td>22.0</td>
<td>CLOSING</td>
<td>23</td>
</tr>
<tr>
<td>23.0</td>
<td>END OF CASE</td>
<td>24</td>
</tr>
<tr>
<td>24.0</td>
<td>THINGS THAT COULD GO WRONG</td>
<td>24</td>
</tr>
<tr>
<td>25.0</td>
<td>MICS-CABG REQUIREMENTS</td>
<td>25</td>
</tr>
<tr>
<td>26.0</td>
<td>CONCLUSION</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>REFERENCES</td>
<td>26</td>
</tr>
</tbody>
</table>

Caution: Not all patients are candidates for beating heart procedures. Some patients would require cardiopulmonary support during surgery.
1.0 INTRODUCTION

Within the context of medical science, cardiac surgery, and particularly coronary artery bypass (CABG) surgery, are relatively young. Although the concept of the etiology of coronary artery occlusion has been known since the late 1800s, it wasn’t until the early 1960s that practical coronary angiography was available to visualize the coronary anatomy. Coronary revascularization started with patch grafts, followed by the use of autogenous saphenous vein grafts and then the use of the internal mammary artery.\(^1\) The early cases were performed with a beating heart, but with the development of cardiopulmonary bypass and cardioplegia, coronary revascularization on a motionless heart became much more feasible.

**EMERGENCE OF CABG SURGERY**

Due to the availability of cardiopulmonary bypass, CABG surgery became significantly more prominent in the 1970s, most commonly utilizing reverse saphenous vein grafts for the better part of two decades. In the mid 1980s, it was determined that the long-term patency of the internal mammary artery graft was significantly higher than the saphenous vein grafts. As a result, the left internal mammary artery (LIMA) became a routine part of the procedure. In the mid 1990s, there was a resurgence of interest in performing the procedure on a beating heart in an attempt to minimize the negative effects of cardiopulmonary bypass. This would become off-pump (OPCAB) surgery. The latest evolution to date has been the push towards minimally invasive cardiac surgery, including MICS-CABG.

**IMPORTANT ROLE OF ANESTHESIOLOGISTS**

As CABG surgery has evolved over the last 5-6 decades, anesthesiologists have been important to the positive outcome of these procedures. Their contribution has become absolutely essential to the development and success of OPCAB and minimally invasive coronary revascularization procedures. Cardiac surgery, in general, is a complex system that requires the vigilance of the entire team. This is even more important with OPCAB and MICS. In addition to a surgical learning curve, there is also an anesthesia learning curve, and the procedure cannot be instituted without anesthesiologists that are completely invested in its success. I was once told by a cardiac surgeon that his decision on whether to perform an OPCAB or conventional CABG depended on which anesthesiologist was supporting the case.

Throughout the evolution of OPCAB and MICS-CABG, there have been monographs and papers discussing the surgical techniques and merits of these procedures but limited information has been directed towards the cardiac anesthesiologist. The purpose of this monograph is to take a closer look at these procedures from the anesthesiologist’s perspective with the hope of facilitating the implementation of these procedures so more cardiac surgery teams can offer the right procedure for the right patient.
2.0 OFF-PUMP CORONARY ARTERY BYPASS SURGERY (OPCAB)

“Noli me tangere” — Latin for “Don’t touch me” — was a phrase that applied very much to the heart in the surgeon’s vernacular and thought process. I have memories of listening to surgical residents being taught in the cardiac operating room, hearing the attending cardiac surgeon say that they always cannulate the aorta first because it is not really touching the heart. The attending would say to cannulate the right atrium last because if there was an arrhythmia, or some other serious event, they would be ready to go onto bypass. I have also seen cardiac surgeons go back onto bypass and re-arrest the heart in order to fix bleeding distal anastomoses.

A PARADIGM SHIFT

The “Noli me tangere” conviction was deeply ingrained in the mindset of the cardiac surgeon, so as you can imagine, the paradigm shift to beating heart procedures has been, and continues to be a slow progression.

The initial defining step towards off-pump CABG started with the MIDCAB (minimally invasive direct coronary artery bypass) procedure. This procedure offered limited options for revascularization and did not require much in the way of mobilization of the heart. I remember being asked to slow the heart rate (HR) to uncomfortable levels to perform the mostly single anastomosis procedure.

In the mid 1990s, the off-pump concept evolved to the OPCAB procedure and the cardiac anesthesiologist had to shift from the relative comfort and lower stress of the time on cardiopulmonary bypass (CPB) to a much more active role and the need to learn a new set of skills in order to manage the hemodynamic perturbations that occurred with lifting the heart.

OPCAB — A NEW LEVEL OF FLEXIBILITY

With the ability to perform OPCAB, a new level of flexibility evolved in order to offer a superior, safer procedure to some patients that may have been precluded from myocardial revascularization such as patients with severely calcified or atherosclerotic aortas, or patients with multiple comorbidities. Additionally, in centers that performed a predominance of OPCAB procedures, the surgeons, anesthesiologists and staff became aware that the patients were less edematous and seemed more alert when CPB was avoided.

NEW SKILLS REQUIRED

Although the information in the literature concerning OPCAB versus on-pump CABG is mixed, the true gauge of the utility of the procedure should be based on the results of practitioners and cardiac surgical teams who are very skilled in performing the procedure. Even institutions that do not perform OPCAB routinely should have the skills necessary to be able to safely perform this procedure to offer the best possible options to their patients with coronary artery disease.

With the evolution of off-pump cardiac surgery, cardiac anesthesiologists had to become skilled at aggressively controlling the hemodynamic alterations that occur with the surgical manipulation of the beating heart that still must maintain perfusion for itself and the rest of the body. We adapted to this new situation by utilizing a deep understanding of cardiovascular physiology and pharmacology. We learned to use all the tools in our armamentarium, including:

### AVAILABLE TOOLS

<table>
<thead>
<tr>
<th>VASOACTIVE AND INOTROPIC MEDICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME REPLACEMENT</td>
</tr>
<tr>
<td>TABLE POSITION</td>
</tr>
<tr>
<td>VISCOSITY</td>
</tr>
<tr>
<td>PACING</td>
</tr>
<tr>
<td>SPATIAL RELATIONSHIPS WITHIN THE CHEST AND MEDIASTINUM</td>
</tr>
</tbody>
</table>

Managing an OPCAB patient also requires the cardiac anesthesiologist to be well-versed in the surgeon’s approach to the procedure, so they can anticipate each step and be prepared.

I will be discussing the procedure based on my own experience in two institutions that were major off-pump cardiac surgery centers.
3.0 OVERVIEW OF THE SURGICAL PROCEDURE

There is some variation in the way surgeons approach OPCAB. Some use the Starfish™ or Urchin™ heart positioners, some primarily use countertraction, and some use a combination of the two. If a retraction suture is used, it is commonly placed between the inferior vena cava (IVC) and the left inferior pulmonary vein in the back of the pericardium (Diagram 1). This requires a significant, but quick, lift of the heart that may severely decrease the blood pressure (BP). This lift should last less than 20 seconds and the BP will return quickly after the heart has been let back down. The pericardial retraction suture placement is the first significant positioning of the heart before the distal anastomosis portion of the procedure.

Once the pericardial retraction stitch is in place, you should start to prepare the heart for the distal anastomoses and the hemodynamic compromise that is associated with positioning.

3.1 LEFT ANTERIOR DESCENDING CORONARY ARTERY (LAD)

This is the least compromising position. The heart is lifted anteriorly and supported by the retraction stitch or possibly the Urchin™ or Starfish™ heart positioners. The Octopus™ pods are placed parallel to the LAD or Diagonal and a little downward pressure is applied to minimize motion around the vessel. (Picture 1)

Diagram 1 – Placement of pericardial retraction suture**

Picture 1 – Positioning for LAD distal anastomosis***

The following are general descriptions of how the heart may be positioned for the different potential targets.

** Property of Medtronic
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3.2 POSTERIOR DESCENDING ARTERY
The apex of the heart is pulled upward so the heart is positioned with the apex pointing anteriorly with the heart upended. This position is supported by the retraction stitch or a positioning device such as the Urchin™ or Starfish™. This position is a little more compromising, but if the heart is lifted gently and given time to adjust, the hemodynamic disturbance is not that significant. (Picture 2)

3.3 RIGHT CORONARY ARTERY (RCA)
If a distal RCA graft is planned, the positioning will be similar to the PDA graft. If a proximal RCA is performed, the Octopus™ will be placed on the right side of the heart. The hemodynamic compromise will be even less. If the plan is to perform a proximal RCA graft, the surgeon should communicate this to the team as heart block may occur, and there should be pacing wires and a pacemaker box readily available.

3.4 CIRCUMFLEX
There is some variation to this positioning. The least intrusive technique is when the surgeon opens the right pleura widely. With the lungs temporarily deflated, the surgeon is able to roll the heart into the right pleural space without compressing it. Ventilation is restarted, the position is aided by the retraction stitch and the Octopus™ is applied to the vessel. If the pleural space is left closed, the heart becomes a little more compressed by the positioning, resulting in more hemodynamic compromise. This becomes a little more challenging, but is still not an insurmountable problem. (Pictures 3 and 4)

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3.5 PROXIMAL ANASTOMOSES

After all the distal anastomoses are completed, the proximal anastomoses are performed. The systolic BP is maintained at a decreased, controlled level; commonly 90mmHg to 100mmHg. Blood pressure control can be accomplished with:

<table>
<thead>
<tr>
<th>BP CONTROL</th>
<th>ADJUSTMENTS TO THE VASOPRESSOR INFUSION(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOLUSES OF VASODILATORS</td>
<td></td>
</tr>
<tr>
<td>GIVING ADDITIONAL ANESTHESIA</td>
<td></td>
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<tr>
<td>MOVING THE TABLE</td>
<td></td>
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</tbody>
</table>

Reverse Trendelenburg is very effective, predictable, and easily reversible by adjusting the table position.

4.0 ANESTHESIA SET-UP

4.1 MONITORING

In addition to the usual standard monitors, an arterial line is essential in all cases to allow the team to immediately determine the effects of cardiac positioning and the effects of the interventions by the cardiac anesthesiologist.

Pulmonary artery catheters (PACs) are commonly placed and can be very helpful. We would frequently place an introducer with a central catheter as a “double stick” if peripheral intravenous access was limited. Some institutions only place a central line in order to have a more reliable administration of vasoactive and inotropic medications. Another option includes the placement of an introducer with a central line insert (some manufacturers have an insert made for the introducer that can be removed to be replaced by a PAC). In this situation, if the patient is having hemodynamic issues post-operatively, the physician has the flexibility of removing the insert and placing a PAC through the existing introducer.

Transesophageal echocardiography (TEE) can be extremely useful and should be used in all cases where there is no contraindication for placement of the probe.

Some of the useful information we can obtain with TEE includes:

- The baseline left and right ventricular function
- Regional wall motion abnormalities (RWMAs) that provide very useful information concerning which target vessels have the most significant impact at baseline and later changes that may reflect issues with positioning or the grafts**
- Cardiac size
- Left ventricular hypertrophy
- Atheromatous disease of the aorta
- Valvular disease
- Idiopathic hypertrophic subaortic stenosis (IHSS) physiology
- Intracardiac shunts
- Pleural effusions

** After (and during) revascularization, we can see significant changes such as improvement in RWMAs, but more critically, worsening of RWMAs or general ventricular function which may signify compromised flow through a native vessel during positioning for a distal anastomosis or a potential technical issue with a graft later in the case.

4.2 MEDICATION SET-UP

BE PREPARED FOR ALL POTENTIAL EVENTS

In addition to the anesthetic agents, the following items should be readily available:

<table>
<thead>
<tr>
<th>SYRINGES OF</th>
<th>EPHEDRINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHENYLEPHRINE</td>
<td></td>
</tr>
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<td>NOREPINEPHRINE</td>
<td></td>
</tr>
<tr>
<td>EPINEPHRINE</td>
<td></td>
</tr>
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<td>NITROGLYCERIN</td>
<td></td>
</tr>
</tbody>
</table>

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<tr>
<th>STANDARDIZED INFUSION THAT INCLUDES</th>
<th>PHENYLEPHRINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORPINEPHRINE</td>
<td></td>
</tr>
<tr>
<td>VASOPRESSIN</td>
<td></td>
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<td></td>
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</table>
4.2 MEDICATION SET-UP
BE PREPARED FOR ALL POTENTIAL EVENTS (CONTINUED)

Vasopressin was initially used to increase the glomerular filtration rate (GFR) to promote urine output on the occasional patient with a sluggish urine output. We found that the patients who had the vasopressin infusion were easier to manage. Eventually vasopressin became a part of our standard infusion set-up and we infused it at 2 U/h in every OPCAB patient.

The benefit of using the push syringes is that a known amount of medication is given, hopefully through a central access, allowing a quick and titratable response that can help the cardiac anesthesiologist to quickly determine if the hemodynamic compromise from the positioning of the heart is manageable. If the heart is lifted and the BP drops quickly, it will take some time to see the effect of adjusting the rate of the infusion of vasopressor, which is usually relatively low. Meanwhile, the BP may continue to drop, or the heart may become ischemic. Also, the surgeon needs to know when it is safe to start the distal anastomosis.

Utilizing a bolus of medication from a syringe to treat acute change in BP due to positioning the heart has predictive utility for management of the hemodynamic changes. A known amount of medication is introduced. The degree of effect from the bolus and the timing of the effect can help to determine the anesthesiologist’s ability to manage the BP.

The following scenarios can illustrate the utility of using boluses:
(Please note that these scenarios are for illustrative purposes only. Exact doses will vary depending on anesthesiologists’ preferences and the clinical situation)

1. The heart is lifted, resulting in an abrupt decrease in BP. The anesthesiologist gives a bolus of 100mcg of phenylephrine but the BP continues to fall. 200mcg are given, followed by 8mcg of norepinephrine. The boluses result in a rapid improvement in the BP to an acceptable level. The phenylephrine and norepinephrine infusions are increased to maintain the beneficial effect during the time it takes to perform the distal anastomosis. This situation is more difficult, but manageable. Tell the surgeon to proceed.

2. The heart is lifted resulting in an abrupt decrease in BP. The anesthesiologist gives a bolus of 100mcg of phenylephrine but the BP continues to fall. 200mcg are given, followed by 8mcg of norepinephrine. After about 10 seconds, the BP begins to slowly increase. In this case, the drugs are working, but have a slow circulation time because of a decreased cardiac output with the current position. As long as the anesthesiologist can see a positive effect of the boluses within a reasonably comfortable timeframe, that person can feel comfortable that they are able to control the hemodynamic changes. In other words, as long as the drugs that are given can circulate and have a predictable effect, it is reasonable for the surgeon to start the distal anastomosis.

3. The heart is lifted resulting in an abrupt decrease in BP. The anesthesiologist gives a bolus of 100mcg of phenylephrine but the BP continues to fall. 200mcg are given, followed by 8mcg of norepinephrine. After about 10 seconds, the BP begins to slowly increase. In this case, the drugs are working, but have a slow circulation time because of a decreased cardiac output with the current position. As long as the anesthesiologist can see a positive effect of the boluses within a reasonably comfortable timeframe, that person can feel comfortable that they are able to control the hemodynamic changes. In other words, as long as the drugs that are given can circulate and have a predictable effect, it is reasonable for the surgeon to start the distal anastomosis.

5.0 ANESTHESIA ISSUES

The following are issues for the cardiac anesthesiologist to consider during OPCAB surgery:

5.1 PRE-LOAD

Pre-load is the primary issue when thinking about the cause for hypotension and the actions to correct it.

When the heart is lifted and compressed between the Octopus™ and thoracic structures (Picture 2 – Page 4) or the retraction stitch, it is not able to fill completely causing decreased pre-load which leads to a decrease in cardiac output, resulting in hypotension and a decrease in systemic perfusion.
5.1 PRE-LOAD (CONTINUED)

The time of positioning is a relatively short, finite period. The objective is to ideally maintain an adequate cardiac output during the distal anastomosis, but if necessary, at least maintain an adequate BP in order to preserve coronary flow (through the stenotic coronary arteries) and myocardial perfusion in order to sustain the heart, even at the expense of cardiac output. Since these periods are short, and get shorter as the surgeon gains experience, the potential decrease in systemic perfusion is of lesser concern.

Prior to positioning for the distal anastomoses, maintain the BP at a level above normal. If the positioning is mild, the BP may not decrease enough to require additional intervention, especially in the face of baseline vascular tone created by the vasopressin infusion and any additional vasopressor infusions that may have been used to achieve the pre-positioning BP.

The following are suggestions for steps to address the decrease in BP with positioning:

1. When the BP starts to fall, consider using Trendelenburg to increase pre-load. This is very effective, results in a quick response, and is easily controllable.

2. Bolus with vasopressors and then increase the infusion. Some anesthesiologists prefer to start with phenylephrine since it is an alpha agonist and can increase BP without increasing myocardial oxygen demand. Other anesthesiologists prefer to use norepinephrine because it is a stronger alpha-agonist and a strong beta-agonist, therefore more balanced and more effective. I personally try to use phenylephrine first, and can sometimes use it for the whole case. If the BP becomes less responsive to the phenylephrine, I would add or switch to norepinephrine.

3. Give volume to keep the patient full and improve pre-load. Early in my experience (when OPCAB was a new procedure), we used more vasopressors and the patients would sometimes have lactic acidosis in the post-operative unit. Subsequently we overcompensated by giving more volume (sometimes 5 or 6 liters) and the patients were volume overloaded post-operatively. Eventually we found a balance and I have noticed that the average, uncomplicated case would receive approximately 3 liters of IV fluids.

5.2 ARRHYTHMIAS

An irregular heart rate (HR) makes the procedure slightly more difficult for the anesthesiologist and the surgeon. When the HR is irregular, the filling time varies in the face of an already compromised pre-load, making it more difficult to maintain a stable BP. In addition, I have been told by one of the surgeons I worked with that it is easier to sew a distal anastomosis when the HR is regular, making the anastomotic time and the time for positioning faster.

Some suggestions include:

- If there are frequent premature atrial contractions (PACs), consider a loading dose of amiodarone, 150mg IV slowly.

- In patients with atrial fibrillation that was not longstanding, we have confirmed by TEE that there was no thrombus in the left atrium and left atrial appendage, then given a loading dose of amiodarone, followed by a synchronized cardioversion. Even if there is not much atrial contribution gained, the regular rhythm helps maintain stability. (Only consider this option if the cardiac anesthesiologist is comfortable assessing for the presence of left atrial thrombus.)

- Premature ventricular contractions (PVCs) can be multifactorial.
  - They can occur from manipulation, positioning, or stimulated by a stabilizer or heart positioner irritating the epicardium. In these situations, a minor change in positioning may result in resolution of the PVCs or they frequently resolve spontaneously.
  - The pulmonary artery catheter (PAC) can occasionally irritate the endocardium of the right ventricle after positioning. This is an easy solution that is often overlooked. Simply pulling the catheter out by 1 or 2cm will frequently help.
  - Ischemia can be a more concerning etiology of PVCs that usually starts several minutes after the start of the distal anastomosis. If the PVCs occur during or immediately after positioning, they are less likely to be secondary to ischemia although the possibility should not be completely excluded. (The treatment of ischemia will be discussed in the next section.)
  - If measures to treat frequent PVCs are not effective, consider treating with amiodarone (if not already given). Also supplement potassium if it is low, and consider giving magnesium sulfate. I would routinely give 4 grams of magnesium for each case.
5.3 TREATING ISCHEMIA

The root concern in managing patients with coronary artery disease, who have atherosclerotic coronary arteries that contain critical stenoses which limit the ability of blood to flow to the myocardium, is driving that blood through the narrowed arteries by maintaining an adequate BP.

The main issue with OPCAB surgery (as mentioned previously) is that positioning the heart may result in a decrease in BP. Depending on the degree of hypotension, some patients will tolerate the drop in BP but some patients may become ischemic.

6.0 AVOID THE ISCHEMIC SPIRAL

We treat the decreased BP by giving vasoactive drugs and/or inotropes. However, if the heart is ischemic, there may be myocardial dysfunction resulting in a decrease in cardiac output which, in turn, will decrease the ability of our drugs to circulate. We give more drugs, but we may not see an effect as the BP continues to drop, the cardiac output continues to decrease, and the heart gets more ischemic.

The best strategy is to act aggressively to keep an adequate BP. If it starts to fall, perform the maneuvers described on page 6 and 7 (i.e. Trendelenburg, vasopressor boluses and infusions, decreasing the intensity of the heart positioning) to get the BP back up.

If you don’t allow the BP to fall, you will be less likely to get into the ischemic spiral.

6.1 FIRST RESPONSE TO ISCHEMIA

In the event that signs of ischemia develop during a distal anastomosis (such as decreased left ventricular function on TEE, ST segment elevation, and unstable hemodynamics) the first response should be to increase the BP. The improved perfusion is frequently enough to resolve the ischemia but once the BP is adequate, there is now opportunity to make other interventions if necessary (such as increasing the nitroglycerin infusion or perhaps giving a short acting beta-blocker to treat significant tachycardia).

6.2 TIPS TO IMPROVE BP

Other tips to help improve BP if you are struggling:

- If the patient has had significant blood loss, the hematocrit (Hct) is dropping, and it is becoming more and more difficult to maintain hemodynamic stability, consider a transfusion of PRBCs to increase the viscosity of the blood. Viscosity is a component of systemic vascular resistance (see the equation below).

\[ R = \frac{8\eta l}{\pi r^4} \]

(Where \( R \) is resistance, \( \eta \) = viscosity of fluid, \( l \) = length of the vessel, and \( r \) = radius)

After considering the risks and benefits of a transfusion, increasing the Hct (and thereby the blood viscosity) will make it easier to maintain an adequate BP.

- Consider giving diphenhydramine 50mg in the event of unstable hemodynamics despite all of the above maneuvers. There may be some vasodilation related to histamine release from one of the previously administered medications or some other unrecognized interaction. If this intervention is successful, consider giving an H1 blocker also.

6.3 SURGICAL CONSIDERATIONS FOR MANAGING ISCHEMIA ORDER OF THE DISTAL ANASTOMOSES

If there is a concern about the degree of disease and impaired cardiac function, it may help to revascularize a portion of the heart by performing, for example, the LIMA to LAD graft first or a vein graft to the RCA and then performing a proximal before proceeding to the other distal anastomoses.
6.3 SURGICAL CONSIDERATIONS FOR MANAGING ISCHEMIA (CONTINUED)

Placement of a Shunt

Occasionally the BP is initially adequate during the distal anastomosis, but sometime after the artery is opened, the heart begins to appear ischemic. This may occur because of a loss of collateral flow. The hemodynamics may be optimized during the early part of the anastomosis, with the BP high enough to adequately supply other regions of the heart and promote collateral flow to the region currently being addressed. Once the artery is opened, the blood will follow the path of least resistance and go out of the arteriotomy instead of going to the myocardium which may result in ischemia.

Despite the signs of ischemia, such as ST segment elevation and declining hemodynamic parameters, if the surgeon moves fast the ischemia will commonly resolve after the vein graft is pulled down to the artery making it harder for the blood to escape.

If the conditions become very unstable, or if the ischemia occurs early in the anastomosis, a shunt (Picture 5) can be placed. This will often immediately improve stability.

** Property of Medtronic

Picture 5 – Shunts**

6.4 STARTING WITH A SEVERELY IMPAIRED HEART

If the heart is initially noted to be dilated with a low ejection fraction (EF), the anesthesiologist should start to optimize the hemodynamic parameters from the beginning of the case.

Some suggestions include:

1. Optimizing pre-load and afterload if possible.

2. Give a milrinone load — 50mcg/kg IVPB over 20 – 30 minutes. Milrinone can be helpful for the following reasons:
   - The inotropic effect will improve biventricular function (increase contractility).
   - By shifting the Frank-Starling curve upwards, the decrease in pre-load resulting from positioning for distal anastomoses will have less of a deleterious effect. (Diagram 2)

** Property of Medtronic

Frank-Starling Curve**

** Baseline — As a consequence of positioning the heart and the resulting reduction in preload (the red line from points 1 to 2 along the curve), the SV will decrease from point A (baseline) to point B.

** Positive inotropic effect curve — Inotropic support will shift the curve upwards, theoretically improving the SV (point C), despite the decrease in preload.
6.4 STARTING WITH A SEVERELY IMPAIRED HEART (CONTINUED)

- The size of the heart will decrease. A smaller heart will be less compressed and therefore less compromised with positioning.

Milrinone can cause vasodilation, but if it is given slowly, the amount of vasodilation is much less and the benefits from the inotropic effect remain. In fact, I have seen patients with significantly diminished ejection fractions have an increase in BP after the milrinone bolus.

3. Consider pacing:
In patients with very slow HRs and difficulty tolerating positioning, the hemodynamic parameters can be optimized by increasing the rate. If the surgeon is able to place atrial wires, the rate can be controlled thereby increasing the cardiac output and BP. For example, if the HR is 45 BPM and the heart does not tolerate positioning, the rate can be doubled to 90 BPM, doubling the cardiac output, and decreasing the size of the heart, facilitating stability with positioning.

4. A small dose of furosemide can also be given if you feel that patient is volume overloaded. The resulting diuresis will also contribute to decreasing the size of the heart, facilitating better tolerance to positioning.

6.5 POST ANASTOMOSIS LV DYSFUNCTION

On occasion we notice signs of ischemia after completion of a distal anastomosis. This may manifest as ST segment elevations and increases in pulmonary artery (PA) pressure. If this scenario occurs, the first action should be to increase the BP. Once the BP is at an acceptable level, the next objective is to decrease the PA pressure. The most reliable way to start is to add reverse Trendelenburg. It is also helpful to give small boluses of nitroglycerin. Once the trend of increasing BP and decreasing PA pressure is initiated, the hemodynamic parameters will almost always continue to progress in a positive direction. It is important to wait until the heart has time to recover before moving on to the next graft.

If air is flushed into the coronary artery, increasing the BP will help this resolve.

7.0 SIGNIFICANT MITRAL REGURGITATION

If previously unrecognized significant mitral regurgitation (MR) is noted on the intraoperative TEE exam, it is likely that the OPCAB procedure can still be performed.

In the presence of significant MR, forward flow through the left ventricle is decreased (decreased cardiac output) and will make maintaining stable hemodynamic parameters more challenging during manipulation of the heart.

Maneuvers/suggestions that may help the situation to be more manageable include:

1. Increase the baseline HR
   - An increase in HR will decrease time for regurgitation and thereby decrease the regurgitant volume resulting in increased forward flow. This should be monitored with TEE to be sure that the increase in HR is actually helping, as it may increase MR in some situations such as severe mitral valve prolapse.
   - The increase in HR will increase the cardiac output, helping to add more stability.
   - If the MR is due to a dilated heart, the increase in HR may make the heart smaller, decreasing the MR.
   - HR can be increased using drugs, but atrial wires give the anesthesiologist more control to titrate the rate in order to optimize the hemodynamic benefit.

2. Use milrinone to increase LV contractility and decrease size
   - The increase in contractility will help with maintaining stability.
   - If the heart size is smaller, the amount of MR may decrease. In patients with mitral valve prolapse, the smaller heart size may potentially make the MR worse.

3. Try to keep the afterload (BP) a little lower, to promote more forward flow. The benefit to forward flow must be balanced with adequate perfusion pressure.
7.0 SIGNIFICANT MITRAL REGURGITATION (CONTINUED)

4. If the MR is thought to be ischemic in origin, it may be possible to perform one or two grafts that require less significant positioning first to improve myocardial perfusion, possibly resulting in some improvement of the MR. If the MR decreases, it may be easier to perform the more demanding grafts.

5. If the MR is dynamic, secondary to IHSS (idiopathic hypertrophic subaortic stenosis) physiology, then maneuvers to decrease the IHSS should be performed before positioning the heart. This etiology is easily diagnosed with TEE by visualizing SAM (Systolic Anterior Motion) of the mitral valve. (Picture 6)

The maneuvers include:
- Give volume
- Decrease the HR
- Turn off inotropes
- Increase the afterload with phenylephrine

6. Consider placing an intra-aortic balloon pump (IABP) if there are no contraindications, as this may also augment forward flow. Of course, the risk of the IABP must be weighed against the risk of CPB in the patient.

7. Use TEE to look at the MR during each position for distal anastomoses. It may be possible to adjust the position in order to decrease the MR.

8. It may be possible to proceed with pump-assist and perform the procedure without arresting the heart.

8.0 PUMP-ASSISTED BEATING HEART SURGERY

Utilizing CPB to provide stability and the ability to perform a multi-vessel CABG procedure with a beating heart is a viable approach that can be used as a bridge to gain experience and comfort with positioning the beating heart. It can also be used in patients that the surgeon feels may not be amenable to OPCAB.

There have been some papers suggesting that pump-assist may be a useful hybrid approach to offer a multi-vessel CABG without the potential risk of aortic cross-clamping and the associated cardioplegic arrest.12-13

** Property of Scott Sadel, MD, FASE
9.0 TEMPERATURE

Since the patient is not on the bypass machine, maintaining a normal temperature is more of an active process for the cardiac surgery team. Some suggestions for maintaining temperature include:

<table>
<thead>
<tr>
<th>TO MAINTAIN TEMPERATURE</th>
<th>WARMING THE IV FLUIDS</th>
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<tbody>
<tr>
<td></td>
<td>USE WARMING DEVICES SUCH AS A FORCED AIR WARMING DEVICE THAT CAN BE PLACED UNDER THE PATIENT OR AROUND THE SIDES AND HEAD</td>
</tr>
<tr>
<td></td>
<td>KEEP THE AMBIENT TEMPERATURE IN THE OPERATING ROOM A LITTLE WARMER THAN USUAL</td>
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</table>

If the team is aggressive at preventing heat loss from the time the patient enters the room, it is very possible to leave the room nearly normothermic.

10.0 ANTICOAGULATION

There has always been variability in the dosing and reversal of heparin in OPCAB surgery.

Our procedure was to initially give 400 units/kg to every patient with the goal of an ACT of > 400 seconds so they would be completely heparinized and ready to go onto cardiopulmonary bypass (CPB) in case of an emergent situation. If the patient received a smaller dose of heparin and became severely unstable, we would have to give additional heparin in order to initiate CPB. Our concern was that the ability of the additional drug to circulate and have the necessary effect could not be guaranteed in the face of a severely unstable situation. In addition, the ACT should be monitored vigilantly during the case to ensure the effect of the heparin does not fall below an acceptable limit in a normothermic patient.

Protamine requirements after off-pump procedures are lower than for on-pump procedures. Our goal for reversal was to keep the post-reversal ACT between 140 and 160 seconds. If there was not an excessive amount of blood loss or coagulopathy during the procedure, the usual initial dose of protamine was 100mg. This was given regardless of the size of the patient or the amount of heparin given during the procedure.

If the initial dose resulted in an elevated ACT, another 25–50mg of protamine usually had a significant effect on bringing the ACT into our desired range.

11.0 OPCAB REQUIREMENTS

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MORE INTENSE ATTENTION TO DETAIL FOR THE ENTIRE TEAM</th>
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<tr>
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<td>MORE AGGRESSIVE MANAGEMENT OF HEMODYNAMICS</td>
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<tr>
<td></td>
<td>A CONTINUOUS STREAM OF CLEAR COMMUNICATION BETWEEN THE ANESTHESIOLOGIST AND THE SURGEON</td>
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<tr>
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<td>AN ADJUSTMENT FOR THE ENTIRE TEAM FROM THEIR NORMAL ROUTINE</td>
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OPCAB surgery is a significant paradigm shift from on-pump CABG. Like any of the other changes we face in life, we feel uneasy leaving our comfort zone, but we adjust, learn, and refine. As we perform more and more cases, what was once foreign becomes routine, and we become more and more comfortable with the new procedure.

Although change can be somewhat uncomfortable, the outcome strengthens the skills of the anesthesiologist and results in the flexibility to offer the most appropriate and the safest procedure for the patient requiring coronary revascularization.
12.0 MINIMALLY INVASIVE CARDIAC SURGERY – CORONARY ARTERY BYPASS (MICS-CABG)

12.1 INTRODUCTION

Surgical procedures, in general, have evolved to become less invasive and patients prefer, and are starting to expect, these “minimally invasive” procedures. The concept of a minimally invasive CABG procedure was started in the mid 1990s in the form of the MIDCAB procedure. This procedure offered limited access to the heart and limited revascularization. MICS-CABG evolved to offer full revascularization via a less invasive approach.

The procedure started in 2005 as the MVST (multi-vessel small thoracotomy). In this first iteration, all the inflow to multiple coronary anastomoses, was taken from the left internal mammary artery.

After some criticism concerning the potential precarious nature of having all of the inflow to the new grafts come from one source, Dr. Joseph McGinn devised a method to access the ascending aorta to perform proximal anastomoses, ultimately resulting in the ability to perform full revascularization through a left thoracotomy with an end result very similar to a CABG performed through a median sternotomy. This is now the MICS-CABG procedure.

As with the OPCAB procedure, the MICS-CABG procedure involved learning new techniques for positioning the heart and accessing the ascending aorta safely for the cardiac surgeon, and learning how to manage the changes in the patient’s hemodynamic parameters as well as maintaining one-lung ventilation for the cardiac anesthesiologist. For both, there were new skills, events to anticipate, and new processes to develop and learn. As we refined the procedure and performed more and more cases, MICS-CABG (like OPCAB a decade before) became a viable, more routine procedure. Eventually it became as routine as performing any other cardiac surgical procedure at our institution.

12.2 ADVANTAGES

<table>
<thead>
<tr>
<th>MICS-CABG ADVANTAGES</th>
<th>SMALLER INCISION/SMALLER SCAR</th>
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<tbody>
<tr>
<td>LESS PAIN</td>
<td>AVOID COMPLICATIONS ASSOCIATED WITH MEDIAN STERNOTOMY SUCH AS:</td>
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<td>§ UNSTABLE STERNUM</td>
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<td></td>
<td>§ BROKEN WIRES</td>
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<td></td>
<td>§ DEEP STERNAL WOUND INFECTION</td>
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<td>§ STERNAL DEHISCENCE</td>
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<tr>
<td>FEWER RESTRICTIONS</td>
<td>THE PATIENTS CAN DRIVE WHEN THEY FEEL UP TO IT</td>
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<tr>
<td></td>
<td>LESS RISK OF INFECTION. THE INCIDENCE OF INFECTION WITH THE THORACOTOMY APPROACH IS EXTREMELY LOW</td>
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<tr>
<td>SHORTER HOSPITAL STAY</td>
<td>QUICKER RETURN TO NORMAL ACTIVITIES</td>
</tr>
</tbody>
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13.0 ONE-LUNG VENTILATION

From the start we decided to use a bronchial blocker instead of a double lumen endotracheal tube for the following reasons:

- We thought the blocker would be easier and quicker to place compared to a double lumen endotracheal tube.
- Since blockers are placed through a regular oral endotracheal tube, there was no need to undertake the risk and time of changing from a double lumen tube to a single lumen tube at the end of the case (if the patient is to remain intubated).
- If the patient had to return to the operating room while still intubated, it was easier, safer, and quicker to place a blocker through the existing oral endotracheal tube instead of having to change the tube to a double lumen tube.
- We tried several types of blockers and found the Uniblocker® to be the easiest to place and the most reliable blocker. The Uniblocker® has a coudé tip that helps direct the blocker into the correct position. We have found that, with a little experience, these catheters can be correctly placed in less than one minute.

13

OFF-PUMP CORONARY ARTERY BYPASS SURGERY — A GUIDE TO MANAGING THE HEMODYNAMIC CHANGES DURING OPCAB AND MICS-CABG
**13.1 TIPS FOR USING THE UNIBLOCKER®**

1. The integrated connector has a port for the fiberoptic scope.
2. Lubricate the blocker and the scope with a sprayable silicone lubricant.
3. Try not to put lubricant on the balloon as this makes it more likely to slip out of position.
4. Position the tip of the blocker approximately 2cm below the carina in the left mainstem bronchus. Accumulation of secretions makes the area around the balloon very slippery. If the balloon is close to the carina and there is a lot of manipulation in the field, the blocker may slip out of position and lung isolation will be lost until the blocker can be repositioned.
5. After positioning, look beyond the tip of the blocker to be sure it is not pushing against a secondary or tertiary carina. The tip extends beyond the balloon and is rigid. Any potential abrasion to the mucosa and resulting bleeding will be exacerbated due to heparinization. The potential for bleeding in the airway can be decreased by checking the tip.
6. At the time of the left thoracotomy skin incision, stop the ventilator and give the lungs some time to collapse (approximately 15 or 20 seconds). Once the left lung is collapsed, inflate the balloon of the blocker and restart the ventilator.

**13.2 STEPS TO INCREASE O₂ SATURATION**

If the O₂ saturation falls at a rapid rate or gradually falls but approaches the low 90s, the following steps are recommended.

1. **Initiate Continuous Positive Airway Pressure (CPAP) to the left lung**
   1. Insert the endotracheal tube (ETT) connector from a #7 ETT into barrel of a 3 cc syringe (Picture 7 A and B). A PEEP set-up can be connected to the ETT connector and the syringe is connected to the open end of the blocker lumen. This technique works very well, but I know of other anesthesiologists who use other methods to connect the CPAP to the bronchial blocker lumen.
   
   ![Picture 7A – Set-up for adding CPAP to the bronchial blocker](image)
   
   ![Picture 7B – ETT connector](image)
   
2. **Start with Positive End-Expiratory Pressure (PEEP) of 5cm H₂O.** We use an adjustable PEEP valve and found that there has to be at least 6 L/min of O₂ flow to generate an adequate effect. If the flow is too high, the lung will be inflated and result in poor visualization in the surgical field.
3. PEEP can slowly be increased to 10cm H₂O if necessary, but at that level, the left lung will usually start to inflate.

2. Try to turn off, or at least decrease, any vasodilators. This includes infusions of nitroglycerin or other vasodilators and some inhalational agents. For example, isoflurane was used for most cases at our institution. During one lung ventilation, I would decrease the isoflurane to 0.8% and supplement with IV anesthesia, using the Bispectral Index™ (BIS™) for guidance. Vasodilators can inhibit hypoxic pulmonary vasoconstriction and result in more blood flow to the unventilated lung causing an increase in shunt and a decrease in O₂ saturation.

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13.2 STEPS TO INCREASE O₂ SATURATION (CONTINUED)

3. If the desaturation has not resolved, the next option is to add PEEP to the ventilated (right) lung
   - If there is some atelectasis in the ventilated lung (and therefore a degree of intrapulmonary shunting) the addition of PEEP may decrease the atelectasis and have a positive effect on the O₂ saturation.
   - If there is no intrapulmonary shunting in the right lung and PEEP is added, the PEEP will increase intra-alveolar pressure, potentially increasing resistance in the pulmonary capillaries. This potential increase in pulmonary vascular resistance in the right lung may cause more blood to be diverted to the left lung, possibly increasing shunt and having a negative effect on the O₂ saturation.
   - Based on the above rationale, applying PEEP to the ventilated lung will occasionally have a positive effect, but may have a negative effect and sometimes does nothing. Therefore, if you are having problems with the O₂ saturation, adding PEEP is a viable option, but if it makes the situation worse, it should be discontinued immediately.

4. If the O₂ saturation is still borderline or not acceptable, the next option is to switch to 2-lung ventilation. We would do this by:
   1. Telling the surgeon what we have tried and that we still have a problem.
   2. The surgeon would pack the left lung.
   3. Once the left lung was packed, we would set the ventilator to 300 or 350cc tidal volume and deflate the balloon of the bronchial blocker.
   4. If the O₂ saturation was still a little low, small (50cc) incremental increases from the baseline tidal volume would usually help.
   5. Changing to 2-lung, low tidal volume ventilation almost always corrects the issues with desaturation.

5. If the O₂ saturation remains low after all the previous steps, consider the possibility of an intracardiac shunt. If the initial TEE for the case revealed a patent foramen ovale (PFO), usually with a left to right shunt, look again to see if the shunt has reversed. Occasionally the positioning of the heart causes a decrease in systemic BP as well as compression of the right heart resulting in a transient elevation of right atrial pressure (RAP). This situation may result in the RAP becoming higher than the left atrial pressure (LAP) causing a reversal of flow through a preexisting asymptomatic PFO, adding to the shunt and desaturation. If this occurs, it may be possible to decrease the amount of intracardiac shunting by:
   1. Communicating the situation to the surgeon.
   2. Using boluses of vasopressors, followed by increases in the infusion rate to increase the systemic BP thereby increasing LAP.
   3. If the stage in the procedure allows, position the patient in reverse Trendelenburg to try to decrease the RAP.
   4. It also may be possible for the surgeon to decrease the intensity of the position, decreasing the compression on the right heart.
   5. If you are able to decrease the RAP > LAP gradient, or shift the gradient back to LAP > RAP, the shunt will decrease or resolve, improving the O₂ saturation.
14.0 PATIENT POSITIONING

The patient is positioned on the operating room table with a rolled sheet running longitudinally under the left side from the scapula down, raising the left side higher than the right side (Pictures 8 and 9). The hip should be positioned at the break in the bed to allow retro-flexion, if needed. The left arm is tucked so the elbow is at the level of the mattress, with the ulnar nerve protected. The right arm is carefully tucked to the side in a normal fashion.

15.0 DEFIBRILLATOR PADS

It is very important to place the defibrillator pads in the correct location. The left pad should be placed high at the left scapula and the right pad should be placed below the nipple and angled anteriorly, medial to the nipple line. This position will be just outside of the sterile field, allowing a potential sternotomy if needed, but will provide the best possible vector for defibrillation given the areas that need to be prepped and draped. (Pictures 10 and 11)

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16.0 TEMPERATURE CONTROL
We used a warming blanket under the patient and a forced air heating device that wraps around the head and extends down the sides of the patient. Due to the left thoracotomy approach, the left limb of the heating device adheres to the left arm, well below the surgical field. The right limb adheres to the patient anterior to the mid axillary line.
We tied a strap (tourniquet) around the left limb of the heating device after skin incision because the vibration from the forced air bothered the surgeon during the LIMA dissection. The strap was removed after the LIMA dissection was completed.

17.0 STEPS OF THE PROCEDURE
As the MICS-CABG procedure evolved and became routine, the stages of the procedure became standard and in some ways different from a median sternotomy CABG. It is important for the cardiac anesthesiologist to know the order of events to anticipate and be prepared for what comes next.

Incision: A 7cm incision is made in the left 4th anterolateral intercostal space as well as 2 small port incisions — one in the left 6th intercostal space and one just below the xiphoid process. (Diagram 3)
17.0 STEPS OF THE PROCEDURE (CONTINUED)

2. LIMA harvest: During the latter portion of the LIMA take-down, it may be necessary to retro-flex the bed to open the thoracotomy incision a little more in order to facilitate better visualization of the superior aspect of the LIMA. It is very important to remember to un-flex the bed at the conclusion of the LIMA harvest as keeping the bed in this position will make it more difficult to maintain stability when positioning the heart for the distal anastomoses.

3. Opening the proximal pericardium: The superior aspect of the pericardium is opened first in order to gain access to the ascending aorta to perform the proximal anastomoses.

In MICS-CABG, the proximal anastomoses are performed first because once the inferior aspect of the pericardium is opened and the heart is out, it is hard to get to the ascending aorta. The proximal anastomoses are completed first and checked thoroughly before moving to the next step.

4. Dissection and mobilization of the ascending aorta — this step of the procedure involves:

   1. Placing the Octopus™ Nuvo (or Octopus™ NS) through the subxiphoid incision and using the Octopus™ to push posteriorly and pull inferiorly on the main pulmonary artery (PA) to gain a line-of-sight with the ascending aorta, which is to the right of the PA. (Picture 14) This will usually cause a mild decrease in BP.

   2. Dissection (mostly blunt dissection) through the mediastinum, around the aorta.

   3. Placing an umbilical tape around the aorta that pulls through a larger gauze strap that will be used to gently roll and retract the ascending aorta towards the left chest. (Picture 14)

   Initially the surgeon was concerned about the possibility of passing the gauze strap around the superior vena cava (SVC) and occluding it while retracting the aorta. If this is a concern, a great vessel view at 0 degrees (Picture 15) will show both the SVC and aorta and should allow you to assuage such concerns. As the surgeon became more experienced with this dissection, concerns of occluding the SVC were almost never an issue.

5. Proximal anastomoses: These are performed one at a time, usually with a side biting clamp, but other devices such as the Heart-String® can be used without difficulty.

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17.0 STEPS OF THE PROCEDURE (CONTINUED)

6. Opening the distal pericardium: This stage is in preparation for the distal anastomoses. On rare occasions, we have seen ventricular fibrillation secondary to using the electrocautery too close to the heart.

7. Checking the distal targets: The intended targets are located. This action serves to identify the proposed distal targets and to test the heart's ability to tolerate a lighter manifestation of manipulations that will be needed in the future. The surgeon would usually make a small scratch mark at the intended distal anastomosis site as a marker.

8. Performing the distal anastomoses.

9. Closure and placement of the pain pump catheters.

18.0 ANESTHESIA SET-UP

Our anesthesia drug set-up was essentially the same as for the OPCAB procedure with the addition of:

<table>
<thead>
<tr>
<th>ADD TO SET-UP</th>
<th>A PUSH SYRINGE OF NICARDIPINE</th>
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<tbody>
<tr>
<td></td>
<td>A BOLUS DOSE OF MILRINONE FOR ALL MICS-CABG CASES</td>
</tr>
<tr>
<td></td>
<td>NICARDIPINE TO THE PUMP SET-UP (OPTIONAL)</td>
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<td></td>
<td>A SYRINGE OF PROPOFOL (OPTIONAL)</td>
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Monitoring was also the same (arterial line, PA catheter, TEE). The only extra consideration is in the event the surgeon plans on cannulating the subclavian artery. The surgeon should communicate the intended cannulation site to the anesthesia team, so they will not use the radial artery on the same side as the intended site of cannulation. If the surgeon cannulates the subclavian artery on the same side as the radial arterial line, the arterial line will be useless as a monitor once CPB is initiated.

19.0 ANESTHESIA ISSUES

1. PREPARING FOR PROXIMAL ANASTOMOSES

When dissection of the ascending aorta is initiated, begin allowing the BP to drift downwards. This is usually achieved by decreasing vasopressor infusions or slightly deepening the anesthetic. The concern is, if the aorta is rigid with pressure it may be more likely to become damaged during blunt dissection. The BP will usually decrease a little with retraction of the PA, but it usually stabilizes quickly.

2. PROXIMAL ANASTOMOSES

When the vein grafts are ready, and it is time to place the side-biting clamp, the systolic BP is decreased to 90–100mm Hg and maintained at that level during this portion of the procedure. The BP is controlled by administering small boluses of nicardipine, or 10-20mg boluses of propofol. It is very important to have tight control of the BP during this part of the procedure since an abrupt increase in BP may result in the side-biting clamp moving out of position or even sliding off the aorta. If this occurs, the field will flood very quickly resulting in zero visibility. The surgeon has a “surgical peanut” available to place over the arteriotomy hole in the event of this situation, but this should not occur with tight BP control.
19.0 ANESTHESIA ISSUES (CONTINUED)

POSITIONING FOR DISTAL ANASTOMOSES

Positioning for distal anastomoses involves three general positions: LAD/Diagonals, PDA, and lateral vessels. During placement of the Starfish™ NS heart positioner, there may be frequent PVCs. This will almost always resolve after the heart positioner is in final position.

1. LAD/Diagonals: This is usually the least compromising position. The Starfish™ NS is placed near the Obtuse Marginal (OM) vessels and the heart is rotated mildly inferiorly and posteriorly to bring the LAD or Diagonal vessel into view within the thoracotomy incision. If the only vessel requiring an anastomosis is the LAD, the Starfish™ NS may not be needed since the LAD can usually be visualized directly under the incision.

2. PDA: To position for the PDA, the Starfish™ NS is placed at the apex of the LV. The apex is pushed superiorly towards the patient’s left shoulder bringing the diaphragmatic surface of the heart upwards into a line-of-sight with the thoracotomy incision. Depending on the size of the heart, the location of the PDA, and the location of the intended anastomosis, it may be necessary to essentially fold the heart. The BP can almost always be managed in this position off-pump. Occasionally we have noted that the PA waveform appears wedged with this positioning. We recommend looking for the tip of the PA catheter with the TEE. The main PA can sometimes be constricted due to the positioning of the heart and the PA catheter is frequently proximal to the narrowed portion. The catheter can then be advanced beyond the narrowed portion with TEE guidance. (Pictures 16, 17, 18, 19 and Diagram 4)

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3. Lateral vessels: To position for the lateral vessels, the Starfish™ NS is placed anterolateral to the apex and the heart is rotated in a counterclockwise direction and pushed medially. Positioning for the OM-1 usually involves little hemodynamic compromise. If the required distal anastomoses are more lateral, the hemodynamic compromise increases. The OM-2 is a little more challenging to maintain, and the Posterior Laterals (PLs) of the Circumflex are even more challenging as the positioning requires more compression of the heart. All of the more lateral vessels can be performed off-pump in many patients depending on the size of the heart, location to be visualized, and the team’s experience. It is possible to initiate pump-assist just for the more difficult anastomoses, limiting the time on the pump.

4. MANAGING HEMODYNAMIC PERTURBATIONS DURING POSITIONING AND DISTAL ANASTOMOSES

1. Optimize hemodynamic parameters prior to starting the case: After the patient is "lined-up", intubated, the blocker is placed, and positioned, it is recommended that a slow milrinone load is initiated over 20-30 minutes (see OPCAB section 6.4) for ALL MICS cases.

2. Pre-load/BP: Try to optimize the pre-load and afterload, if necessary, so the patient has an acceptable cardiac output prior to manipulation of the heart. As discussed in the OPCAB section, try to have a good BP prior to positioning the heart. When the BP drops, use Trendelenburg, alpha agonists, and give volume.

3. Trendelenburg: Because most operating tables bend in the middle during Trendelenburg positioning, it is important with MICS-CABG to only perform this maneuver when the Starfish™ NS heart positioner is on the heart. The Starfish™ NS and Octopus™ devices are attached to the rails on opposite sides of the bed at different locations along its length. If both devices are attached to the heart and the bed bends in the middle during Trendelenburg positioning, instead of improving pre-load, the heart may become more compressed as both devices push from different directions.

4. Choice of pressors and inotropic drugs:
   - Phenylephrine should be the first choice, using boluses and infusion. Since phenylephrine is only an alpha agonist, it will increase BP without affecting contractility.
   - If norepinephrine is needed, it should be given in very small boluses, using a higher rate of infusion to maintain the BP. Because norepinephrine is a potent beta agonist, it will frequently cause the heart to become more dynamic. Depending on the stability of the positioning at the time, the increased cardiac motion may be a technical problem for the surgeon (increased motion while sewing the anastomosis or causing the stabilizer to slip out of position).

5. Arrhythmias: Treatment of arrhythmias is the same as for OPCAB (please refer to that section) except for bradycardia.
19.0 ANESTHESIA ISSUES (CONTINUED)

6. Bradycardia: Because of the limited access via the small thoracotomy incision, it may be harder to place pacing wires. If significant bradycardia is an issue in managing the hemodynamics, and the surgeon is not able or willing to place pacing wires, the following may help:

- **Drugs** — Ephedrine 5 or 10mg IV and/or glycopyrrolate 0.2 – 0.4mg IV are frequently enough to increase the HR. Atropine may also be helpful as a next step, although there is a risk of increasing the rate too much. A dopamine infusion can also be tried.

- **Pacing** — We always placed a Paceport™ PA catheter (Picture 20 and 21). A pacing wire can be placed by the anesthesiologist to help increase the HR.

ANTICOAGULATION
This is the same as with OPCAB (see section 10.0).

20.0 CANNULATION FOR PUMP-ASSIST

If there is a concern that the patient will not be able to tolerate the procedure or a portion of the procedure off-pump, cannulation for pump-assist is mostly performed by the femoral artery and vein, or the femoral vein and subclavian artery approach. This could be done in the beginning of the case if the likelihood is high that pump-assist will be needed. If it is just a concern, the physician assistant who preps the patient would mark the groin based on exam or possibly ultrasound guidance in order to facilitate quicker access to the femoral artery and vein.

Anesthesia staff would assist with femoral cannulation by using the TEE to help the surgeon direct the guide wire and the cannula into the SVC (Pictures 22 and 23) and making sure the wire from the femoral artery travels proximally into the descending thoracic aorta. (Picture 24)

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21.0 PAIN CONTROL

We routinely used an On-Q™ pump. A sub-pleural catheter was placed prior to closing, and later, a second catheter was placed in the incision. The pump was filled with 0.25% bupivacaine and lasted for 5 days. If the catheters are well placed, the amount of post-operative pain was impressively diminished.

22.0 CLOSING

Prior to closing the chest:
1. The balloon of the blocker is deflated.
2. The lung is manually inflated very slowly as the surgeon watches the lung expand.
3. The surgeon makes sure that the lung passes under the LIMA and there is no traction on the vessel.

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23.0 END OF CASE

At the end of the case:
1. Remove the blocker. It is a good idea to look into the airway with the fiberoptic scope one last time. If there is blood in the airway, try to suck out as much as possible.
2. As with any cardiac surgery case, the team should monitor the chest tube output prior to leaving the room.
3. It is a good idea to perform one last TEE exam just prior to leaving the room to be sure there is no accumulation of fluid in the pericardium or the pleural spaces.
4. Transport the patient to the ICU with monitors.
5. We would aim to extubate the patient 2–6 hours after arrival in the ICU. This would give the intensive care team time to make sure the patient is stable, warm, and not bleeding.

24.0 THINGS THAT COULD GO WRONG

It is always better to learn from other people’s mistakes, so I have included a list of problems that have occurred during the early learning curve of the MICS procedure.

1. RIGHT PNEUMOTHORAX
   During this case we had difficulty with the O₂ saturation and BP through most of the case, although the problems were not insurmountable. After all of the anastomoses were completed, the surgeon found a right tension pneumothorax. This must have occurred during the dissection across the mediastinum.

2. FORGETTING TO UN-FLEX THE BED
   If you forget to un-flex the bed, the team will have to work harder during the distal anastomosis portion of the case. It is an easy thing to forget, and can make the case much more difficult.

3. LOSS OF LUNG ISOLATION
   This situation will usually manifest with the ventilator alarming to indicate high peak inspiratory pressure and the end-tidal CO₂ waveform showing diminished amplitude because the blocker balloon is now in the trachea. Placing the balloon approximately 2cm below the carina will decrease the incidence of this occurring, but it may still occasionally happen with heavy manipulation in the left chest.

4. LACERATION OF THE SVC
   In one case, there was bleeding from the right side of the mediastinum that turned out to be a small laceration in the SVC.

5. UNABLE TO DEFIBRILLATE
   If the defibrillator pads don’t work when needed (usually because they were not correctly placed in the beginning of the case), it is very important to have pediatric paddles readily available on the field. These can be placed through the thoracotomy incision and used effectively.

6. TAMONADE
   Early in our experience the positioning of the heart resulted in a degree of maceration of the epicardium and subsequent oozing. Ongoing oozing may potentially result in tamponade. This should be considered with any post-operative instability, even though it is very rare in our experience. The issue with epicardial maceration eventually resolved as the anesthesia team learned how to optimize cardiac size and hemodynamics, and the surgeon learned how to place the devices and position the heart more effectively.

7. RETAINED MATERIAL
   Whenever a procedure occurs though a small incision with limited visibility, it is very important to be sure the count is correct so nothing is left behind.
25.0 MICS-CABG REQUIREMENTS

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A PARADIGM SHIFT FROM MEDIAN STERNOTOMY</td>
</tr>
<tr>
<td>EVEN MORE MULTITASKING COMPARED TO OPCAB</td>
</tr>
<tr>
<td>MORE AGGRESSIVE MANAGEMENT OF HEMODYNAMICS</td>
</tr>
<tr>
<td>A SIGNIFICANT LEVEL OF COMMUNICATION BETWEEN THE CARDIAC ANESTHESIOLOGIST AND THE CARDIAC SURGEON</td>
</tr>
</tbody>
</table>

26.0 CONCLUSION

The path of least resistance is always the easiest path but is not conducive to advancement and, in the case of cardiac surgery, may not be the best for our patients. Changing a long-standing mindset and leaving our comfort zone may be challenging but can eventually lead us, as professionals, to offer our patients more options and ultimately less risk and better outcomes.

OPCAB and MICS-CABG require the entire team to adjust to a significant paradigm shift from a routine procedure that hasn’t changed much in decades. The process of learning and adjusting is worth the effort in developing improved skills for the cardiac surgeon and the cardiac anesthesiologist. But, most importantly, it opens the door for a new level of flexibility to offer the best possible, and safest procedures for our patients.

The goal should be to offer the right procedure for the right patient.
References


Caution: Federal law (USA) restricts this device to sale by or on the order of a physician. For a listing of indications, contraindications, precautions and warnings, please refer to the Instructions for Use.

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