EXPERIENCE, INSIGHTS AND TECHNIQUES FOR CARDIAC SURGEONS AND THEIR TEAMS

OPCAB Procedure Guide
Paul Sergeant, MD
BIOGRAPHY
PAUL SERGEANT, MD

Paul T. Sergeant is a cardiovascular surgeon with a medical license from Gent University, Belgium. His general and cardiothoracic surgical training includes extensive periods in the U.S., Netherlands and Israel. His academic career at KU Leuven, Belgium, spans more than 30 years, where he retired in 2014. His PhD on Hazard Analysis in CABG is based on an extensive short-and long-term database of thousands of patients that was promoted by Eugene Blackstone, MD. In the clinical realm, Prof. Sergeant focuses on adult cardiac surgery. Possessing a passion for education and training, he is an information officer for the European Association of Cardiothoracic Surgery (EACTS) and founder of Cardiothoracic Surgeons Network (CTSnet) where he serves as president and board member.

Initially, Prof. Sergeant held some apprehension about OPCAB — but through extensive discussions with Paul Grundeman, a Principal Investigator of early stabilization techniques, Prof. Sergeant ultimately converted. He continued on the OPCAB path, implementing the essential components of learning, as recognized by the science of learning: conceptual, induced, operational and virtual into his own daily performance of CABG procedures.

Prof. Sergeant has proctored more than 900 three-day training sessions in Belgium and conducted over 100 sessions in 40 countries. Exposure to and working with the formalization of operational learning, as introduced and lead by him continues to inspire and benefit many, including the visiting teams of surgeons, anesthesiologists and nurses. This experience continues to encourage the essential driver towards the reduction of risks for the patient.

This information is provided as an educational resource to practitioners based on an identified need, but is not intended to constitute medical advice or in any way replace the independent medical judgment of a trained and licensed physician with respect to any patient needs or circumstances. Please see the complete Instructions for Use for products discussed or demonstrated, including all product indications, contraindications, precautions, warnings, and adverse events. These materials are prepared using trained surgeons, who have been using these products regularly within their practices, and the ease of use and outcomes may be different when used by untrained or inexperienced practitioners.
**TABLE OF CONTENTS**

1.0 INTRODUCTION/GOALS AND OBJECTIVES .......................................................... 1

2.0 PLANNING OPCAB SURGERY .............................................................................. 2

   2.1 THE OPERATING THEATER ............................................................................... 2

   2.2 THE ANESTHESIA SET-UP .............................................................................. 3

   2.3 THE PATIENT SELECTION ............................................................................... 3

3.0 AT THE START OF SURGERY: ANESTHESIA MANAGEMENT ........................ 5

4.0 SURGERY: THE PERICARDIUM ......................................................................... 7

5.0 SURGERY: THE ANTERIOR WALL VISUALIZATION, THE STABILIZATION AND ARTERIOTOMY INCISION .............................................................. 9

6.0 SURGERY: THE SHUNTING ............................................................................... 10

7.0 SURGERY: THE ANASTOMOSIS ....................................................................... 12

8.0 SURGERY: THE PROXIMAL ANASTOMOSIS .................................................... 13

9.0 ANESTHESIA AND SURGERY: THE CAUSES AND RESPONSES ON ISCHEMIA DURING ANASTOMOSIS .............................................................. 14

10.0 ANESTHESIA AND SURGERY: CONCEPTS OF ENUCLEATION ............... 15

   10.1 THE ANASTOMOTIC STABILIZER .................................................................. 16

   10.2 THE APICAL POSITIONER ............................................................................. 17

   10.3 THE DEEP PERICARDIAL STITCH/TAPE ....................................................... 18

11.0 ANESTHESIA AND SURGERY: A COMBINATION OF ENUCLEATING METHODS ........ 20

12.0 SURGERY: ANASTOMOTIC ISSUES ................................................................... 22

13.0 A MULTIFACTORIAL APPROACH TO AVOID STROKE .............................. 25

SPECIAL SECTION: IMPLEMENTING OPCAB—UNDERSTANDING THE ISSUES AND LEARNING CURVE ................................................................. 27

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

**USER TIPS**

Chapters marked with this symbol include links to videos found on our [OPCAB webpage](#). Videos are also available on the OPCAB Procedure Guide flash drive, provided by your Medtronic representative.

(iPad) SWIPE to navigate pages

TAP PAGE NUMBER to return to TABLE OF CONTENTS

Navigate content by TAPPING the chapter listed
INTRODUCTION

Many techniques have been described in OPCAB surgery, some have proven to be more substantiated and some failed. The OPCAB surgery technique described herein is the result of the collective experience of Prof. Sergeant and the many surgeons, anesthetists and nurses that have collaborated with him over the span of his career in Leuven.

This technique has been successfully applied to thousands of consecutive CABG patients and trained in younger surgeons. Conversion rates are approximating 1%. Prof. Sergeant is convinced that alternative approaches are possible, however this concept has been taught to more than 1300 visiting surgeons, anesthetists and nurses from more than 60 countries.

1.0 GOALS AND OBJECTIVES

**Goals:**
To implement the OPCAB approach for the benefit of the patient

**Objectives:**
- Structure the OPCAB team and its interfaces
- Nursing staff sets-up the operating theatre, provides instruments, devices and supports the surgical process
- Anesthesia staff monitors, understands and responds to ischemia and hemodynamic failure
- Surgeon staff stabilizes, shunts and anastomoses in the OPCAB environment

The operational learning process becomes optimal when:
- The reduction of the conversion rate to on-pump is as low as possible
- The early mortality and morbidity vs. on-pump CABG is equal or better
- The late benefits of on-pump CABG have not been compromised
2.0 PLANNING OPCAB SURGERY

2.1 THE OPERATING THEATRE

Due to the reduced airspace, during lateral wall OPCAB revascularization, some additional or different instruments are needed. The traditional needle holder will need to be replaced by a Castroviejo, at least 23-cm in length. The unstable or moving target surface forces the surgeon to work with an open needle holder (without or with open hatches) during the needle passage of the vessel walls. A rounded-off handle of the needle holder and forceps will facilitate the rotation of the instrument without moving the stabilized surgical hand. The incision of a coronary vessel in reduced airspace does not allow the use of an angulated Potts scissors; as a consequence straight shaped micro-scissors should be available. The required instruments for a conversion should be available in the operating room, but do not have to be on the surgical tables. A number of surgical tools have been developed to help the surgical team.

RETRACTORS

Sternal retractors have been modified so that additional stabilizing devices can be properly anchored. Two additional types of devices are further proposed, the anastomotic stabilizer and the apical positioner. Both of these devices have known major developments. The first original anastomotic stabilizers were compression and friction stabilizers. Compression stabilizers deform the natural shape of the cardiac surface, which is potentially deleterious.1 In my experience, the optimal stabilizer is a suction stabilizer, respecting very much the natural shape of the heart.

APICAL POSITIONERS

The apical positioners are used to enucleate and displace the cardiac shape and come in two formats, a suction cup with a predefined outer ring and a triad of suction surfaces. The anastomotic suction devices as well as the apical positioners demand separate vacuum control units. Each of these suction units mandates different controls and different vacuum settings.

CORONARY SHUNTS

An additional and essential device is the coronary shunt. The shunt allows the continued perfusion of the coronary outflow area during most of the anastomosis time.

MISTER BLOWER

Many surgical teams employ the mister blower to clear the anastomotic area from blood by blowing a mist of CO₂ gas and fluid over the region.

MAGNETIC MATTRESS

Many surgical set-ups consist of an adjustable high table positioned above the patient’s abdomen. Such a setting will create a conflict when the legs of the patient are elevated. We have replaced this with a sterile magnetic mattress.

WARM ROOM

The operating theatre is warmed to 24°C (75°F) before the patient enters the room and this temperature is maintained until the draping of the patient. The patient is lying on a water or preferably gel-based warming mattress. If careful attention has been made to patient temperature loss, then no sterile warm-air blankets are needed. After draping, the room temperature is lowered to 20°C (68°F), but it needs to be stated that the patient’s temperature remains a priority and if needed, a higher operating theatre temperature is maintained.

OTHER CONSIDERATIONS FOR THE OPERATING THEATRE

Beyond the scope of this document is the possible consideration of the use of the Intra-Aortic Balloon Pump, Extracorporeal Membrane Oxygenation or left/right ventricular assist device in the operating environment. Since our approach is a no-touch aorta approach, we do not have epiaortic scanning devices readily available.

ENUCLEATION

Enucleating the heart will induce some volume shifts. These shifts will demand positional changes of the body, such as rotation of the body and elevation of the legs. A table that allows separate elevation of the legs is preferable for OPCAB.

PERFUSION

With greater experience, and conversion rates below 1%, it was felt acceptable to maintain a perfusionist presence in the hospital, but not necessarily in the actual operating theater.
2.2 THE ANESTHESIA SET-UP EXTRACORPOREAL CIRCULATION SUPPORT AND MONITORING

When a patient is supported by an extracorporeal circulation, it does not really matter whether the heart is beating or not, functioning or non-functioning. In the OPCAB mode any variance from normal functioning will need to be identified in real-time, preferably beat-to-beat, allowing the earliest possible therapeutic and procedural response.

An arterial line in combination with a peripheral and a central line initiate the monitoring. Ischemic activity of the heart is monitored through a multi-lead ST monitor and a trans-esophageal echocardiography (TEE). Both have important limitations in monitoring ischemia during displacement of the heart during the grafting of the postero-lateral walls of the heart. Perhaps the most important hemodynamic variable in the monitoring of ischemia is the left ventricular end-diastolic pressure (LVEDP) and wave form. Some groups prefer to introduce a left atrial catheter while others, including our group, rely on the pulmonary capillary wedge pressure (PCWP) as a surrogate for LVEDP. Indeed left ventricle (LV) stiffness is one of the earliest signs of myocardial ischemia. A quadrangular change of the pulmonary wave form is a warning signal similar to an unexplainable increase of PCWP pressure. The TEE is useful in the assessment of regional wall motion in the pre- and post- revascularization period but during enucleation this is difficult through a loss of acoustic coupling. Pulse induced contour cardiac output monitoring (PICCO) is an alternative.

The incidence of intraoperative awareness is high in cardiac surgery. To avoid the reflex of decreasing the dose of anesthetics in the presence of hemodynamic instability and avoid intra-operative awareness, we recommend using bispectral index monitoring, particularly in the first phase of the OPCAB learning curve.

The second most important aspect of monitoring the heart is the visual monitoring by surgeon and anesthesiologist throughout the entire procedure. They monitor the general shape, the color of the cardiac surface (any variability in color will be considered variability in perfusion), the waves of depolarization, the interaction between apical and anastomotic stabilizers with the cardiac structures and the coronary vessels.

2.3 THE PATIENT SELECTION

The preparation of an optimal OPCAB procedure starts with patient selection in relation to the used OPCAB concept utilized. Critical understanding of the clinical condition and the coronary angiogram and or echocardiogram identifies issues demanding more extensive experience, a variance in surgical strategy during OPCAB or a non-OPCAB approach.

CONTRAINDICATIONS

A patient undergoing CPR or in severe cardiogenic shock (CO less than 1/M²) is an absolute contraindication. Any manipulation of the heart will induce ventricular tachycardia or fibrillation. Moderate cardiogenic shock (CO between 1-2 L / M²) in combination with pulmonary edema or low saturation is also an absolute contraindication, because the failure of the pulmonary system will drive the patient into a possibly lethal negative spiral. Moderate cardiogenic shock without pulmonary failure becomes a relative contraindication, certainly when IABP is available, but demands highly committed experience and teamwork.

Some very committed and experienced teams may consider moderate cardiogenic shock without pulmonary failure a relative contraindication in conjunction with IABP.

A fine-tuned titration of inotropic support balanced with peripheral dilation is acceptable here. Conversion should not be considered a failure of the surgical approach, but an effort to reduce the already present pulmonary congestion.

A very critical left main stenosis is no absolute, but becomes a relative contraindication when combined with hemodynamic and electrical instability; this is due to a higher level of knowledge and skills required from the team. Without this combination, it is perfectly normal to have an OPCAB approach with an appropriate revascularization strategy. A deep intramural or intraseptal coronary pathway is no absolute contraindication, but demands a wider experience in OPCAB. This requires mastering an additional technique and skill — and some additional tools.
CORONARY VESSEL VARIABILITY
The anatomical variability of the coronary vessels needs to be studied in relation to the positioning of the anastomotic stabilizer and apical positioner. As an example, a diagonal vessel that extends to the apex, can interface with apical positioning. Two coronary vessels in the immediate vicinity of each other demands specific transformations of the stabilizer. Vessel pathology, stenosis and bifurcations can create issues for shunt positioning and perfusion leading to possible consequences on the grafting sequence and strategy. It helps to identify these issues before the start of the procedure.

MITRAL INCOMPETENCE
The presence of mitral incompetence can influence the surgical strategy towards a combined valvular coronary procedure but is not a relative or absolute contraindication for the OPCAB approach. In these cases with a fragile mitral valve plateau, any enucleation of the left ventricle will need to follow even stricter concepts and monitoring.

A chronic very low ventricular ejection fraction demands a very strict application of the monitoring, enucleation and stabilization process. No deformation of the left ventricular cavity or change in mitral valve incompetence is acceptable and therefore the anastomotic technique and instrumentation will need to be adapted to the reduced airspace. This clinical situation in an acute setting of active or recent ischemia is one of the most challenging and it demands extensive experience. While it is rather easy to displace large left ventricular volumes, it is very difficult to displace ventricles suffering from massive left ventricular hypertrophy. Certainly if these ventricles have incurred a recent infarct they may have zones of lesser compliance. A gradual build-up of team experience will facilitate the OPCAB approach in these clinical settings. An appropriate anesthetic approach, considering beta-blocking agents and restricted use of inotropes could make the difference.

DISCUSSION WITH PATIENTS
Whether the OPCAB patient should go into a fast-track process after surgery is a discussion that exceeds the scope of this guide. In some units nearly all patients are included in such a process, whether they were treated on- or off-pump; in other units hardly any such patient follows this type of track. There is no reason why OPCAB patients, in the absence of massive comorbidity, should not have this opportunity proposed.

The team’s approach to the procedure should be conveyed to the patient which would include early and late benefits as well as the possible consequences.

The discussion whether to discontinue anti-aggregant medication before surgery is a matter of debate. In the last ten years, it has not been our routine to discontinue this type of medication. All other cardiac medication such as beta-blocking agents or similar is continued.

From the start of the day of surgery, strict attention will be focused on the preservation of patient body temperature. This starts in the ward room and continues to the draping of the patient in the operating rooms. The operating room is optimally warmed to 24°C (75°F) before the patient arrives and this temperature needs to be maintained until draping. The use of heating blankets is a more expensive alternative when normal processes have failed.
3.0 AT THE START OF SURGERY: ANESTHESIA MANAGEMENT

General anesthesia is still the most common type of anesthesia for off-pump coronary artery surgery. Thoracic epidural anesthesia in an awake patient has also been used for this type of surgery but there are no known convincing clinical trials published to date. Thoracic epidural anesthesia in a sleeping patient is not used routinely since most of our patients are on anti-aggregative medication. General anesthesia covers several aspects that require close control in the pre- intra- and postoperative care of surgical patients. It consists not only of an adequate induction and maintenance of unconsciousness but also of the continuous titration to proper (i.e. adjusted to the type of surgery) levels of analgesia, amnesia, neuromuscular blockade and stress control.

PHARMACEUTICAL APPROACH

For each of these separate pharmaco-dynamic goals the modern anesthesiologist uses a multitude of different drugs. Current developments in the field have produced pharmacological agents with favorable pharmacokinetic properties allowing a fast onset and offset of their effects. For the anesthetic management of patients undergoing OPCAB surgery there is no reason to select “special” drugs. The one evolution that has occurred over the past few years is the gradual omission of the “high dose opioid” technique. The use of high dose opioids to obtain unconsciousness offers great hemodynamic stability at the expense of prolonged postoperative respiratory depression. The novel ultra-short acting opioid Remifentanil® is the only exception to this. Recent studies have shown that the addition of low doses of a hypnotic drug safeguards the patient from experiencing unintentional awareness. It is clear that several combinations of drugs are being used with success in a variety of medical centers.

MANAGING ANTI-COAGULATION

In OPCAB surgery, the management of anticoagulation no longer needs to focus on the prevention of CPB-induced activation of the coagulation system with high-dose heparin, but hypercoagulability, thromboembolic phenomena and graft patency issues have been shown to occur in OPCAB patients. We have never observed these issues, but for that reason we still opt for full heparin doses to obtain an ACT of 400 seconds, demanding 3-mg/kg or more if needed. There is a linear relationship between time and the logarithmic scale of heparin. In consequence the ACT is measured every 15 minutes and top-up doses of heparin are administered when ACT is below 400 seconds.

Protamine is used at a 1 to 1 ratio (or 0.8 to 1) for reversal of the heparin effect at the end of the anastomotic time. The use of prophylactic anti-fibrinolytics agents was not standard.

BLOOD MANAGEMENT

All blood loss during the complete interval of the procedure is recovered in a heparinized system and reservoir. This is only washed if more than one unit can be saved and given to supplement a Hgb level below 9-g/dl or at the surgeon’s discretion. Blood products are only given in the presence of proven abnormal anticoagulation.

We have observed, that a major challenge during OPCAB surgery exists in managing the cardiovascular volume changes that occur with dislocation of the heart during exposition of the latero-posterior wall. This may possibly be associated with kinking of systemic and pulmonary veins or an increase of mitral valve incompetence. Preload decreases acutely and cardiac performance drops suddenly.

We favor the following hemodynamic conditions during the entire procedure:

<table>
<thead>
<tr>
<th>HEMODYNAMIC CONDITIONS</th>
<th>HEART RATE BETWEEN 55 TO 70- BPM SINUS RHYTHM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SYSTOLIC ARTERIAL BLOOD PRESSURE &gt; 85-MMHG AND DIASTOLIC ARTERIAL BLOOD PRESSURE &gt; 50-MMHG</td>
</tr>
<tr>
<td></td>
<td>CVP &gt; 5-MMHG AND PCWP 10 &gt; &lt; 18-MMHG</td>
</tr>
<tr>
<td></td>
<td>CARDIAC INDEX &gt; 2 L/MIN / M²</td>
</tr>
<tr>
<td></td>
<td>NORMOXIA, NORMOCARBIA AND NORMOTHERMIA</td>
</tr>
</tbody>
</table>

Remifentanil is a registered trademark of Glasko Smith Kline.
VOLUME CHANGES
The treatment of hemodynamic volume changes is based on an understanding of the pathophysiology involved. Preload decreases may be caused by right ventricular outflow compression, an obstructed inferior and/or superior caval and/or pulmonary venous return, an increase of mitral valve incompetence caused by destabilization of the mitral valve plateau or an increase in left atrial volume (with constant filling) induced by elongation at elevation of the heart. The surgeon-anesthesia interface, guided by appropriate monitoring, will communicate these findings in real time and induce the appropriate response in the surgical field or by anesthesia. Lower filling pressures are often associated with atrial electrical instability. The systemic and pulmonary venous return is primarily preserved by elevating the legs.

Trendelenburg is avoided due to its compromise on superior vena caval return with possible cerebral consequences. Colloids are administered to maintain a central venous pressure > 8-mmHg or PCWP above 12-mmHg. Higher filling pressures are accepted in the presence of COPD, atrial fibrillation or severe left ventricular hypertrophy. In these circumstances higher filling is normal and essential for normal cardiac output.

VASODILATION
Vasodilatation in the presence of a normo-thermic body can also induce a decrease in afterload. Pharmacological increase of afterload may improve collateral coronary perfusion. The decision to increase afterload depends on the preexisting ventricular function. In severely depressed ventricles, low doses of inotropic support are administered in combination with vasopressors. In all other patients we absolutely avoid inotropic support and administer alpha 1 agonists because they decrease venous capacitance (improve preload) and have a pharmacological preconditioning effect (G-protein coupled).

ELECTRICAL INSTABILITY
Electrical instability in OPCAB surgery has surgical and electrolytic causes. This instability has major hemodynamic consequences, therefore our approach is absolute avoidance, even of a single PVC.

Sinus bradycardia below 55-bpm is treated by placing atrial pacing leads and pacing at the discretion of the anesthesiologist. A physiologic heart rate will also improve the cardiac output, reduce the ventricular cavity and facilitate the displacement of the heart. Sinus tachycardia above 70-bpm can be caused by an insufficient level of anesthesia, a decrease in filling or insufficient beta-blocking agents. This is treated accordingly. If additional beta-blocking agents are needed, long-acting drugs are preferred versus short-acting, to guarantee the coverage for the duration of the procedure. Tachycardia is often the first sign of ischemia and if nitroglycerin is not already infusing, a nitroglycerin infusion is started and continued throughout the procedure. Left Bundle Branch Block, Right Bundle Branch Block or Left Anterior Hemiblock (LBBB, RBBB or LAHB) can easily lead to complete AV block in the presence of ischemia. The safety of the conduction in these patients might be guaranteed from the start by placing AV sequential pacing and the availability of a pacemaker. Chronic atrial fibrillation does not facilitate the enucleation or the surgical technique. This can be solved by placing ventricular leads, additional beta-blocking agents and over-pacing where needed. A very proximal right coronary artery anastomosis and its possible reduction of flow during the anastomosis have been reported to be associated with complete AV block or an AV junctional rhythm. To address this (AV or V) pacing leads are placed, but this should not be considered an alternative to shunting.
Cell excitability is strongly influenced by the extracellular potassium concentration, the major determinant of the resting membrane potential. If the extracellular potassium concentration is higher, the cell membrane concentration decreases. This extracellular potassium can easily be influenced by causing an intra-to-extra cellular ion shift by changing the blood pH or administering glucose and insulin or by infusion of potassium. We monitor potassium constantly and maintain this above 4.1-mmol/L. PVCs are considered the early warning signs of ischemia. They are therefore additionally avoided by reducing or eliminating the contact between the hand of the surgeon and the cardiac surface. Magnesium sulfate, due to its pivotal role in cardiac excitability, neuromuscular transmission and vasomotor tone is given in a preventive manner in almost all patients at a dose of 25-mg/kg. At times Xylocaine® and Diltiazem® might be considered, however not routinely used.

The blood glucose level is constantly monitored and maintained between physiological levels. Where possible, gases and infusion lines are brought to normal patient temperature.

_Diltiazem is a registered trademark of Teva Pharmaceutical Industries Ltd.
Xylocaine is a registered trademark of AstraZeneca._

### 4.0 SURGERY: THE PERICARDIUM

The sternal retractor is placed after the incision of the skin. It is somewhat easier to have the transverse bar cranially. Note that 90% of the vertical sides and the transverse bar are appropriate for mounting the stabilizer. Make sure that an optimal retraction is obtained in the lower part of the mediastinum. A suboptimal widening of the superior mediastinum is of less importance. For the stabilization of the anterior wall we place the mounting clamp of the stabilizer, at the lowest part of the right arm of the sternal retractor and the articulating arm swings as low as possible over the abdomen and the diaphragm. The arm is used to stabilize the surgical hand.

Several surgical options exist for opening the pericardium and chest cavities. Our approach is driven by the use of both internal thoracic arteries in nearly all procedures and by our enucleation concept. We only open the pericardium after the harvesting of both internal thoracic arteries, to reduce the time of exposure of the open mediastinum. We open both pleural cavities to allow maximum length and mobility of these grafts. In the rare patients where no right ITA graft is used, the right pleural cavity is not opened since the heart isn’t enucleated in this cavity. A contemporary discussion regarding the variety of bypass conduits exceeds the scope of this document. We make four pericardial incision lines.
OPENING THE PERICARDIUM

LINE 1
Vertical axis incision along the midline.

LINE 2
The most important element follows: It is a horizontal incision along the diaphragm, on the right side towards the right pleural cavity, on the left side towards the left pleural cavity so that the left ventricular apex becomes visible and can then be moved unobstructed.

LINE 3
Intended to lower the left internal thoracic artery as much as possible away from the sternum and to optimize its length. It incises the left superior pericardium up to and after visualization of the phrenic nerve and is extended in parallel to the phrenic nerve.

LINE 4
On its right side, line 4 is similar to line 3 and is only applied when an in-situ right internal thoracic artery is used. This in-situ graft is used for extremely severe proximal right coronary artery stenosis, possibly also for diagonal or intermediary vessels-stenosis in the presence of a sub-occluded left main coronary artery.
5.0 SURGERY:

The LAD and its septal and diagonal tributaries is the coronary system with the largest outflow area. If the angiogram, confirmed by fractional flow measurements, identifies a critical stenosis or even a complete occlusion, then this area is frequently vascularized before other areas of the heart. The lateral, posterior and inferior regions of the heart are approached after grafting the anterior region. The ventricle is not touched by hands or instruments other than the stabilizer, to avoid even a single PVC. Usually the diagonal vessels are vascularized before the LAD.

At opening of the pericardium, the LAD is visible at the left outer side of the open space, without visibility of the diagonal side branches. Only the left side of the pericardium is suspended to the chest wall, creating a minimal rotation of the left ventricle and some additional exposure. Considerable additional exposure is created by placing a horizontal line of separate retraction stitches in the left pericardium. Start at the left upper side of the pericardium, at the level of the pulmonary valve and pull the heart up gently. The stitch is fixed to the sternal towels immobilized by the sternal retractor. The next stitch proceeds towards the diaphragm, parallel to the phrenic nerve and goes lower versus the previous one. Gradually the complete anterior wall is exposed. Attention is given to the fully expanded lung behind this pericardium. Usually three or four of these separate stitches are needed. This approach is insufficient for access to the intermediary vessels.

The anastomotic site on the coronary vessel (diagonal or LAD) is chosen based on the grafting strategy, the graft, shunting and the stabilization of the anastomotic area. We use only suction anastomotic stabilizers due to their respect for the ventricular shape and cavity. The current models consist of two stabilizing pods with four suction cups. Any coronary vessel, in particular a large vessel such as the LAD, should avoid compression by the stabilizers. We therefore always try to stabilize the diagonal vessels, whatever their axis, by placing the anastomotic stabilizer parallel to the LAD. If the tip of one of the two stabilizing zones would touch the LAD, then this tip is everted upwards to avoid all contact. If the stabilizing zones would be too close to another coronary vessel, then the two branches are gently spread apart further, doubling the space between the pods, although with some loss of stability. The negative pressure is between (-350) and (-400)-mmHg. The anastomotic area is now stabilized within the pods of the stabilizer. To further reduce some longitudinal or lateral movement, we place additional secondary stabilizing stitches within the epicardium in the direction of the instability (these are tagged with small instruments such as mosquito hemostats).
The insertion of the shunt demands a disease-free area of the coronary vessel in the last centimeter before the incision; in addition any bifurcation immediately before or after the anastomotic site will bring shunting at risk through selective perfusion or obstruction of flow. These aspects are taken into consideration before the anastomotic site is decided.

Any change in position of the coronary vessel, as caused by stabilization, can induce ischemia. This is most valid during stabilization of large and sometimes tortuous vessels as with the proximal RCA. A high level of bidirectional communication between surgeon and anesthesia is needed during this period.

Before the arteriotomy incision is made, it must be decided if the shunt will be inserted in a bloodless field or not. Our general concept is to never place a temporary clamp or ligature distal to the anastomotic area. Under normal circumstances a proximal tourniquet is applied with an elastic ligature (4-zero monofilament round needle) or loop. There are two possible exceptions to this. The first is when the coronary vessel has an intraseptal or intramural pathway with unknown depth. The second situation is with an occluded vessel, often with an inverted or retrograde coronary flow. In both of these circumstances no proximal or distal tourniquet is applied. Bleeding is controlled through pushing on the proximal part of the vessel with a small sponge.

6.0 SURGERY: THE SHUNTING

Grafting a coronary vessel means that one considers the area at risk of ischemia. Not shunting a coronary vessel during the anastomotic phase dramatically increases the risk of a sudden appearance of ischemia and possible conversion. We therefore always shunt, even in the presence of an occluded vessel. The preservation of the existing collateral flow is critically important. In addition there is a risk of total AV block if a proximal right coronary artery is occluded and grafted without shunting; even more in the presence of LBBB, RBBB or total AV block. The safety in these last conditions is always increased by having sequential pacing in place, even if a shunt is used.

In addition the presence of a shunt optimizes the anastomotic shape and reduces the risk of outflow or inflow stenosis. This is most valid in the presence of very small coronary vessels. The shunt insertion process starts by interfacing with the anesthesiologist about the conditioning of the patient. If necessary the incision, shunt insertion and the creation of the anastomosis is postponed.

The flow through the shunt is dependent on the mean perfusion pressure and the internal lumen of the shunt. A 2-mm shunt with a 70-mmHg perfusion pressure will easily give 40-cc of flow per minute. We therefore always try to insert the maximum size shunt in relation to the internal lumen of the coronary vessel. Insertion of any sized shunt will always create a gradient on the intraluminal distal coronary perfusion pressure. We believe the more severe the proximal stenosis or the smaller the open lumen, the lesser the consequences on gradient. If a severe stenosis allows a flow of 40-ml/min and the shunt allows 35-ml/min, then there will be only a minimal gradient.

This is certainly at risk to happen if a previously inserted ITA graft is now used as inflow for a new graft and is shunted during the connection, as in repeat procedures. The ITA graft, for example may allow 80-ml/min but the shunt would only allow 45-ml/min.

A shunt placement can damage the walls of the coronary vessel. Therefore we believe the shunt placement process should be learned and practiced in a stress-free low-fidelity simulation environment until a smooth insertion process is obtained. Some scholars may need to simulate this hundreds of times before being able to perform this stress-free. Only then will it be placed in the real setting with stress, blood and reduced air space.
After shunt insertion, the surgeon evaluates the flow in the distal coronary bed, the color of the epicardial surface and the twirling moves of the distal coronary vessel. It is important at this time to communicate the shunt positioning to anesthesia. A gas-blowing device is often used to clear the anastomotic region from blood dissipating along the shunt. This device can create a temporary air lock in coronary arteries and therefore direct injection of air into coronaries is avoided.

If ischemia is observed during shunt use there may be a number of causes and therapeutic options available:

- **Malpositioning of the Shunt**: The surgeon must always evaluate if the shunt is properly inserted in the coronary vessel proximally and distally. In very deep intra-mural coronaries, malpositioning is more likely to occur. The surgeon must evaluate if the shunt does not obstruct the flow proximally or if there is distal selective perfusion in a bifurcation.

- **Dysfunctioning of the Shunt**: In the presence of shunts reinforced with a metal spring, the surgeon can pinch the spring and thereby obstruct the internal channel.

- **Insufficient Flow Through Shunt**: If the two previously mentioned causes have been ruled out then the shunt size needs to be considered. The first and most efficient approach is for the surgeon to consider the placement of a larger shunt. This can double the delivered flow for the same perfusion pressure if a 0.5-mm larger shunt can be used. The anesthesiologist may also increase the perfusion pressure. This will increase the collateral flow but will only have a minimal impact of the flow through the shunt due to the flow characteristics through a shunt.

- The surgical team must consider that non-shunt factors could have caused ischemia. Simultaneously all efforts towards conversion are initiated but conversion is not started unless the previous approaches were shown to be ineffective.
7.0 SURGERY: THE ANASTOMOSIS

Once the shunt is placed, the anastomosis can start.

Many surgeons continue to use 7-0 suture with a needle length of 9 or 11-mm. While this is possible in sufficient airspace as on the anterior surface of the heart, it becomes very difficult to navigate with these very large needles in reduced airspace. In addition, a typical 7-0 suture makes a 250-micron hole in the wall, whereas an 8-0 needle makes on average 150-micron holes. We strongly advise therefore to use an 8-0 suture with a 6-mm needle to facilitate the anastomotic process. The passage of the needle through the moving coronary vessel wall has to be done with an open/unlocked needle holder to reduce the penetration trauma.

The anterior wall airspace allows a parachuted or non-parachuted technique, but the other surfaces with potentially reduced airspace often require a non-parachuted technique. In addition the parachuted technique may induce a possible sawing effect on the vessel wall creating penetration trauma, most certainly in a moving coronary artery. We have adapted our anastomotic method for all anastomoses to the non-parachute technique, demanding higher technical skills but highly adapted to anastomoses in reduced airspace on moving targets.

OPCAB anastomoses are deconstructed into teachable components and learned in low-fidelity simulation.
8.0 SURGERY: THE PROXIMAL ANASTOMOSIS

In our earliest OPCAB experience we performed proximal anastomoses on the aorta at an average of 1.2 proximals per patient. We often used epiaortic scanning to optimize the proximal anastomotic site and avoided any clamping if the aorta was diseased as diagnosed on angiogram, TEE or visually. Our OPCAB approach in combination with this low proximal anastomotic rate has halved the prevalence of major and minor strokes from 1.5% to 0.7% in a consecutive series of more than 3000 patients. We considered this an insufficient reduction and have deleted all manipulation of the aorta to the no-touch aorta approach. We now consider any manipulation of the aorta in the OPCAB approach as an inconsistent and incomplete concept, but very rarely needed.
9.0 ANESTHESIA AND SURGERY: THE CAUSES AND RESPONSES ON ISCHEMIA DURING ANASTOMOSIS

In our experience, we noticed that the causes for ischemia in OPCAB are multifactorial. It all starts with the refinement of ischemia monitoring tools: from a single PVC to a quadrangular change in the wave form of the pulmonary artery pressure. The worse the early warning sign, the more difficult the response will be. The next element is the surgeon-anesthesia interface that has to function cohesively to obtain an optimized response.

When ischemia is identified before the anastomotic interval then it is considered to be due to an imbalance between demand and conditioning. This is most often due to:

- The heart rate moving outside of physiological criteria, too fast or too slow
- The systolic perfusion pressures being outside of physiological criteria, too low and insufficient coronary perfusion and-or collateral flow, or too high and demanding too much heart work. The systolic pressure needs to be related to the end diastolic pressure. A higher end-diastolic pressure will demand a higher perfusion pressure.
- Insufficient filling
- Inotropes given inappropriately. Work load will increase the oxygen demand in a patient without revascularization. We therefore avoid inotropes as much as possible.
- Insufficient optimization of collateral flow or coronary perfusion, which can be treated with nitroglycerine or magnesium.

When ischemia is identified during the anastomotic interval then the previously mentioned causes remain valid, and additional causes of supply become plausible:

- The stabilizing or enucleating devices occlude or touch a coronary vessel. This could be a deep pericardial stitch, anastomotic stabilizer or apical positioner.
- The shunt creates a gradient in the insufficiently stenosed coronary vessel, obstructs the inflow proximal or distally, or the shunt gives selective perfusion into a distal bifurcation.

When ischemia is observed after the anastomotic interval, then the same causes as before the anastomotic interval remain active but additional causes of supply become plausible:

- A graft or anastomosis malfunction is the most common possibility.
- Due to repositioning of the left ventricle, existing ischemia, which has been present before but not recognized due to the absence of the Triangle of Eindhoven, now becomes visible. Care must be taken when using cup-shaped apical positioners with fixed outer rims in order to prevent risk of pressing and occluding the LAD. When they are removed ischemia may become apparent. In both of these last circumstances this ischemia will disappear rapidly, if not other causes should be sought. For this reason we have moved away from using these types of positioners.
**10.0 ANESTHESIA AND SURGERY: CONCEPTS OF ENUCLEATION**

The goal of a perfect enucleation is to allow a perfect anastomosis and to maintain the physiology of the heart or to be able to correct it in real-time.

These goals need to be translated in a number of measurable objectives. We therefore need to monitor all these different measurable objectives before we can accept an enucleation process.

Several methods have been proposed but not all have monitored the objectives or have been able to reach them. Often some of these methods have been combined to correct or improve the consequences or the performance. First we provide our subjective assessment of the effects of various enucleation methods, and then the description of a limited number of the methods follows.

The independent and the combined effect of an enucleating tool on leverage, hemodynamics and visibility.

---

**MEASURABLE OBJECTIVES**

- **VISIBILITY**
  - STABILIZATION OF THE VENTRICLE
  - STABILIZATION OF THE ANASTOMOTIC AREA
  - ELONGATION OF MYOFIBRILS
  - CHANGES IN MITRAL VALVE PLATEAU
  - PULMONARY PressURES AND WAVE FORM
  - PVC, HEART RATE, CARDIAC OUTPUT, ISCHEMIA

---

**EFFECTS OF ENUCLEATION**

<table>
<thead>
<tr>
<th>METHOD</th>
<th>LEVERAGE</th>
<th>HEMODYNAMICS</th>
<th>VISIBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>RETRO-CARDIAC SPONGE/ PROSTHESIS</td>
<td>+</td>
<td>+</td>
<td>++ ANTERIOR --- POSTERIOR</td>
</tr>
<tr>
<td>CROSS-YOUR-HEART TAPES</td>
<td>+++</td>
<td>---</td>
<td>+++ ANTERIOR ++ POSTERIOR</td>
</tr>
<tr>
<td>ANASTOMOTIC STABILIZER AS ENUCLEATOR</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>APICAL POSITIONER, SUCTION CUP (SC)</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>APICAL POSITIONER, SUCTION SURFACE (SS)</td>
<td>++</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>DEEP STITCH, OUTSIDE 4 PULMONARY VEINS QUADRANT</td>
<td>+</td>
<td>---</td>
<td>+</td>
</tr>
<tr>
<td>DEEP TAPE, INSIDE 4 PULMONARY VEINS QUADRANT</td>
<td>+++</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>DEEP TAPE IN COMBINATION WITH APICAL POSITIONER (SS)</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
</tr>
</tbody>
</table>

+++ very good, ++ good, + average, --- totally unacceptable, -- unacceptable, - not good
10.1 THE ANASTOMOTIC STABILIZER

METHOD
An anastomotic stabilizer is used to enucleate and simultaneously stabilize the left ventricle as the anastomotic region. The arm of the stabilizer can take two different trajectories. In trajectory one the arm comes from the top with the tip of the stabilizer pointing downwards; in the second trajectory the arm comes from the top and goes all the way towards the bottom of the pericardium, rotates down and upwards pushing on the left ventricle with the tip of the stabilizer pointing upwards.

LEVERAGE
The leverage is very inefficient in our experience when using a stabilizer for heart positioning. There is no support from the bottom (except maybe in that second trajectory) and the only effect created is a right lateral displacement of the left latero-posterior surface. In the second trajectory (toes up) the space is taken by the arm in going downwards and rotating. This requires so much space that the rightward displacement becomes massive and pushes the ventricle towards and into the right chest cavity.

HEMODYNAMIC CONSEQUENCES
The torque of the heart is not controlled, so the heart has a tendency to rotate out of the stabilizer. The negative suction of the stabilizer (between -300 and -400-mmHg) does not compensate for this torque. Therefore all stabilization can be lost in the middle of an anastomosis. This can be somewhat corrected by deploying one pod of the anastomotic stabilizer and creating a spoon shape, to support and control the lateral dislocation of the left ventricle. It is obvious that now only one pod of the stabilizer is actually stabilizing the anastomotic region.

- There is no physical contact with the cardiac surface and its structures, except by the pods of the anastomotic stabilizer.
- PVCs are often observed due to the unstable stabilization.
- The left ventricular axis is not elongated, so there is no deleterious effect on the contracting myofibrils.
- The left atrium-left ventricular axis is considerably disturbed with possible consequences on the stability of the mitral valve plateau. Pulmonary artery or left atrial pressure monitoring is strongly recommended.

- A considerable non-physiological ventricular shape deformation is created by this method (most pronounced by the second trajectory) with compression of the left lateral wall. We have found this creates incomplete filling and depressed contraction with a drop in cardiac output. These negative changes may not be corrected using inotropes because this is a physical effect.

VISIBILITY
Visibility is acceptable, except to the more proximal portions of the coronary vessels. It is nearly impossible to follow the tracts of the proximal coronaries down into the left atrial-ventricular groove. In addition if the coronary vessel has an intra-myocardial tract, the exposure becomes very critical. Indeed for this situation, spreading of the stabilizer pods is necessary which may lead to a reduction in stabilization.
10.2 THE APICAL POSITIONER

METHOD
An alternative tool in the enucleation process is the apical positioner. This comes in two shapes: a suction cup (SC) with a circular predefined outer ring, and the other device with a three-appendage suction surface (SS) that adapts to the cardiac surface. The round suction cup with a pre-defined outer ring is placed directly on the apex. This is the only place where the cup comfortably fits. The three-appendage apical positioner can adapt to flatter surfaces, yet it is easier to apply to curved surfaces. It can theoretically be placed on the apex, but is optimally placed on the left anterolateral surface of the heart, just lateral to the LAD. The suction force on the apical positioners differs and ranges from (-250) to (-400)-mmHg. This high negative force is needed to maintain large ventricles in the suction zone if no additional method of support is used. A negative force of this dimension creates a risk of hematoma, even rupture, in the presence of exaggerated traction or of ventricular structures in older patients or in patients with reduced connective tissue (steroid therapy). In later sections, we will show it has been possible to reduce this negative pressure to (-200)-mmHg with either suction device.

LEVERAGE
The leverage obtained with either device is rather good since the longitudinal axis of the left ventricle can be changed from a left lateral axis to an axis pointing completely upwards.

HEMODYNAMIC CONSEQUENCES
- The hemodynamic consequences as an isolated approach can be considerable. They are due to the local effect of the suction and the longitudinal traction on the myofibrils.
- The left atrial-ventricular axis is distorted since this enucleation method has no effect on the left atrium. In consequence, pulmonary artery or left atrial pressure monitoring is strongly recommended.
- A left ventricle, in our experience, enucleated only by an apical positioning device and not by any bottom-supportive device, loses up to 15 to 20% of its relaxation and contractility, due to elongation of the myofibrils. This was recreated in our own sheep study. This effect may not be apparent in the presence of normal or moderately reduced ventricular functions but may have major consequences in the presence of low ejection fractions. Since this effect is induced by physical force, no medication will be able to compensate for this effect. The elongation cannot be monitored directly, only indirectly.
  - PVCs are often a sign that the elongation of the left ventricle has reached its maximum tolerance.
  - The suction cup, in our experience, has a somewhat better holding force, but the consequence is that the left ventricle is engulfed in the cup shape. A reduction of up to 8-10% in cardiac output is often observed using these devices. The smaller the left ventricle (as in petite older females), the larger this effect.
  - In the presence of very low ejection fractions where the lateral, posterior and inferior ventricular contractility is lost due to infarction, the effect of engulfing the only contractile anterolateral surface in the cup can totally destabilize the hemodynamic condition.
  - It is theoretically possible to place that cup on another cardiac surface but this is not very easy with the predefined outer ring (much easier with the three-suction surfaces). Any sign that could be attributed to ischemia, even a single PVC, should lead to questioning the possible negative effects of the apical suction device and require the immediate repositioning or removal of this device. If ischemia has been caused it should disappear within seconds after removal. Likewise with the use of the tri-appendage apical positioner, there is a similar risk of suctioning on top of an anatomical variant with a very large diagonal vessel running all the way to the apex. This will need to be identified preoperatively during the reading of the coronary angiogram.
  - The weight of the heart should be supported by some system or device, and should not remain on the base of the mediastinum and flipped upwards.

VISIBILITY
The visibility of the more proximal vessels on the left lateral and posterior surface, where they come out of the coronary sinus, is very reduced, since there is no elevation of the basis of the left ventricle. The middle and distal sections of these coronary vessels are very visible. This visibility is enhanced by the elongation (not exceeding the normal) of the shape of the left ventricle increasing the anastomotic airspace. The air space for the enucleated lateral wall is the space between the cardiac ventricular surface and the retractor or pericardium.
10.3 THE DEEP PERICARDIAL STITCH/TAPE METHOD

Several teams use one form of “deep stitch” but considerable variability exists in the type of stitch/tape and positioning of the anchor.

There is a material variability of the pericardial anchor. It is possible to use sutures or slings: a suture point is anchored (tied or not) deep in the posterior mediastinum or a tape is transformed into a two-pronged shape, then fixed by a tourniquet or a ligature at an anchor point. If a tourniquet is used then this must be a very long and stiff tourniquet (such as a tracheal suction tube), allowing the Kocher-instrument that closes the tourniquet to be positioned outside of the chest.

The leverage effect with the suture is obtained by elevating the posterior mediastinum. It is possible that the suture causes friction and trauma on the left ventricular wall. The leverage effect of the tape is obtained by letting the posterior mediastinum in place but by having the heart in a cradle composed of the two prongs of the tape. When the tape is used the mass of the ventricle will be maintained carefully between the two branches of the tape during the enucleation process. The two branches will be separated from one another to allow this positioning and will follow-up the enucleation effect towards inferior or superior, as needed.

The positional variability of the pericardial anchor(s) often was not driven by strict three-dimensional and pressure monitoring of the anatomical structures of the heart. It was driven more by the easy visibility on the posterior mediastinum. A two- or a three-hand maneuver will create different access to the posterior mediastinum.

The right hand takes the ventricle out of the pericardial cavity and the left hand takes the enucleated heart, thereby liberating the right hand for suturing. In this two-hand enucleation of the left ventricle with the left hand of the surgeon, the posterior pericardium lateral and inferior to both left pulmonary veins is exposed and one or several stitches are placed (sometimes tied) starting laterally of the left pulmonary vein to adjacent of the inferior caval vein. The intention is to pull the posterior pericardium, fixed to the posterior mediastinum, upwards and the heart, placed in this posterior pericardium as in a cradle, moves upwards out of its normal axis. The axial movement of the ventricle is not controlled and will vary according to shape and size of the left ventricle.
A three-hand maneuver increases visibility on the posterior mediastinum. The left hand of the surgeon enucleates the heart and passes it to the right hand. This right hand is placed on the inferior surface of the left ventricle and avoids the gliding of the ventricle away from the hand with a small sponge between the hand and the ventricle. The left hand of the surgeon comes again in the surgical field and moves as far in as possible, between the left and right inferior pulmonary veins with one (for small ventricles) and up to three fingers. This maneuver enucleates the ventricle completely but also lifts the left atrium upwards; the further the finger(s) the better this effect. The surgeon now has visibility of the complete posterior mediastinum inside as outside of the square formed by the four pulmonary veins. This complete zone can now be used for placement of the deep stitches. In the three-hand maneuver only tapes are used. The intention is to anchor a single two-pronged tape as high up as possible under the left atrium and between the two superior pulmonary veins, the higher the better the leverage. The surgeon must understand the three-dimensional nature of the regional anatomy in having the esophagus right under the posterior mediastinum. The anchor stitch of the tourniquet must take sufficient width but very shallow depth. The deep stitches/tape, anchored within the quadrant, will leverage the left atrium and the left ventricle in one block and maintain the atrial-ventricular axis. The cradle of the tape will further enhance this leverage.

HEMODYNAMIC CONSEQUENCES
The hemodynamic consequences will vary according to the position and material variability of the anchor stitch(es). All anchor points not placed under the left atrium and therefore outside of the space defined by the four pulmonary veins, distorts the linear atrial-ventricular axis and possibly the mitral valve plateau. This distortion can create or increase mitral valve incompetence and overload the pulmonary volume. Extensive displacement towards or inside the right chest cavity creates torsion and strangulation of the inferior and superior caval veins. The hemodynamic effect will be the loss of filling, resulting in electrical instability and possible premature ventricular contractions to ventricular fibrillation/ventricular tachycardia (PVC to VF/VT) and hemodynamic instability (loss of output).

If the anchor stitch is placed within this pulmonary vein quadrant then a perfect enucleation can be obtained repeatedly without any hemodynamic effect. By lifting the atrium, the size of the left atrium increases and the pressure generated by the same amount of blood in the left atrium will decrease. If this process is done slowly then the changes in filling will have minimal effect. The basis of the heart is elevated, the atrial-ventricular axis is preserved and the ventricular axis points upwards. The leverage is so perfect that a new issue can arise. Indeed this ventricular axis is not stable, except in the presence of left ventricular hypertrophy. This instability of the ventricular axis issue needs to be addressed as it can create PVCs.

VISIBILITY
The deep stitches placed outside of the pulmonary vein quadrant elevated the heart only partially since they only bring the pericardial cradle upwards for the few centimeters or inches that the posterior pericardium allows. Additional methods, in combination with the heart positioner, are often used to obtain additional visibility or the anastomosis is performed under very reduced visibility.

If the deep stitch is placed within the quadrant and if a tape is used, a perfect visibility is obtained. The visibility is suboptimal in the presence of severe left ventricular hypertrophy as in any previously cited method, due to reduced anastomotic airspace.
11.0 ANESTHESIA AND SURGERY: A COMBINATION OF ENUCLEATING METHODS

It becomes evident that a strict process of enucleation is required to consistently achieve optimal hemodynamics, visibility and stabilization. Using a combination of methods has allowed junior and senior surgeons, including anesthesiologists to encounter consistent parameters as described.

The first element needed is a perfect enucleation or leverage effect without effect on the atrialventricular axis. This is obtained with a deep tape placed within the pulmonary quadrant. So this element will be the essence of the method. One limitation of this method is the axial instability — certainly in the presence of very elongated ventricles. A second limitation is the reduced airspace in the presence of severe left ventricular hypertrophy. Both limitations are solved by adding a tri-appendage apical positioner, placed on the anterolateral area, immediately adjacent to the LAD and avoiding the diagonal vessels. The limitation of the apical positioner was the high suction force when used as a standalone method. Since the ventricle is already enucleated and supported, the apical positioner will only demand a minimal suction force, approximately (-200)-mmHg.

THE APICAL POSITIONER

- WILL NOT BE USED IN THE PRESENCE OF A VERY SMALL VENTRICLE
- WILL NOT BE USED WHEN ONLY THE ANTERIOR ZONE OF THE HEART IS BEING GRAFTED
- WILL NOT BE PLACED ON A LARGE DIAGONAL OF THE LAD RUNNING IN THE LANDING ZONE

STEPS FOR ANESTHESIA AND SURGERY WHEN ENUCLEATING THE HEART

STEP 1
Interface with anesthesia and request permission to start the first step of the process. The conditioning of the patient should be perfect, including filling of the heart, absence of ischemia and physiologic values for ions.

STEP 2
Have a small sponge in the right hand. Place the left hand in the chest and take the ventricle out of its pocket. Pass the ventricle from the left hand to the right hand and maintain the heart using a small sponge to avoid slipping. Scoop the left atrium by inserting from the inferior side towards cranially one or several fingers under the left atrium and as far as possible and lift the left atrium upwards. Make sure not to squeeze the heart under the left forearm. If the heart is not allowed to fill, then it will not eject. Practice this maneuver having the aorta cannulated.

STEP 3
Place a 3-0 100-cm long polypropylene suture in the pulmonary quadrant, as high up as possible and be aware of the route of the esophagus. Do not use the inflow pulmonary veins; their structure is not solid enough. Bring the needle out the chest and return the heart to its physiologic position. From the first touch of the heart to the return, only 5 to 7 seconds should be needed. Allow the hemodynamics to return to normal. With minimal experience this can be done without any reduction of filling and ejection.

STEP 4
Place a long and stiff tourniquet around the previously inserted 3-0 suture and place a long and wet sponge through the open eye of the tourniquet then divide it into two equal lengths of sponge thus creating a two-armed structure, which will become the sling.

STEP 5
Interface again with anesthesia and request permission for the second maneuver. Use the left hand to displace the left ventricle and use a solid forceps in the right hand to push the sponge down in the open space all the way down to the anchor point. The first assistant or nurse follows downwards with the tourniquet and affixes it with a solid forceps. Place one prong of the sponge more upwards and one more downwards. The surgeon returns the heart to its physiologic position. This maneuver should take less than 3 to 4 seconds. Allow the hemodynamics to return to normal.
STEP 6
Interface for a third time with anesthesiology and agree on starting the enucleation process. The anesthesiologist monitors the systems as well as the surgical field. The surgeon monitors only the surgical field.

The two prongs should be separated around 4-cm from one another and the mass of the left ventricle around halfway in between. If the distance between the prongs is too close the ventricle will slide one way or the other; if it is too wide the ventricle will not enucleate.

STEP 7
Very slowly elevate and pull the two prongs towards the left side of the chest, with the intention of giving as much space as possible for the left ventricle to enucleate. The heart is slowly elevated and the prongs repeatedly adjusted in function of the pathway followed by the left ventricle to maintain optimal control. Not a single PVC should be observed. The anesthesiologist is given time to respond to the changes in filling by elevating the legs. Trendelenburg is avoided by all means. If needed, additional volume or selective vasoconstrictors are given. The whole process can demand a few minutes and should result in a full erectile left ventricular axis.

STEP 8
If the ventricular shape is rather oblong, it is possible to observe an axial instability of the erectile left ventricle. This can create PVCs and even have minor hemodynamic consequences. If the ventricular shape is round, the airspace between the left ventricular wall and the retractor is minimal and sometimes even absent. Both of these issues are solved by placing a tri-surface apical positioner. In fact we use an apical positioner in nearly all cases to facilitate the procedure.

The apical positioner is placed on the right arm of the sternal retractor and as high as possible. The negative suction needed to control the movements of the heart can be reduced from the proposed (-400)-mmHg (as in some apical positioners) to (-200)-mmHg, because the ventricle is completely supported from the bottom up. If too much elevation tension is applied, the positioner will disconnect before it creates any trauma.

The positioner is placed in the left zone lateral to the LAD with two appendages pointing towards and the third away from the LAD. The LAD is avoided as is the diaphragmatic surface of the right ventricle, because the suction will disconnect at the first manipulation of the positioner. When mobilizing the axis of the left ventricle, it is important to maintain the longitudinal axis and not just displacing the actual apex.

At this moment, inspection can be done of the anatomy and the surgical strategy is finalized, avoiding simultaneous exposure of all the lateral, posterior and inferior vessels. This is not mandatory and will be difficult in the presence of severe left ventricular hypertrophy.

STEP 9
The anastomotic stabilizer is now fixed to the retractor. The position on the retractor depends on the anastomotic target. For all targets from the first lateral coronary vessel to the second lateral branch of the circumflex vessel, the stabilizer is fixed at the most inferior part of the right arm of the sternal retractor. For all targets beyond the second lateral up to the posterior descending coronary vessel, it is preferable to fix the stabilizer on the superior part of the left arm of the sternal retractor. Otherwise the pod of the stabilizer comes into the airspace needed for viewing the anastomotic area. The pod of the stabilizer will always point downwards towards the posterior mediastinum.

STEP 10
In the presence of severe left ventricular hypertrophy, the airspace is often very reduced. It is possible to increase this airspace by transforming the two pods of the stabilizer into a spoon shape, by creating a linear curvature and bending them inwards. They will further enucleate and control the anastomotic region. The most distal portion of the arm of the stabilizer should not touch the cardiac surface. This is obtained by adding a small angulation of the pods.

An anastomosis on the posterior descending artery will demand a different transformation of the anastomotic stabilizer. Indeed the diaphragmatic surface is flat and therefore the two pods of the anastomotic stabilizer will be returned to their original shape before stabilizing.
ANASTOMOTIC ISSUES

ANASTOMOSES IN REDUCED AIRSPACE

Anastomoses in reduced airspace demand a very rigorous training and preparation. If possible the coronary vessel is aligned in the line of vision of the surgeon. This allows very good visibility on both sides of the grafted vessel, reducing the chances of inversion.

Traditional anastomotic techniques use a parachuted approach. In this approach the graft and the host are held at a distance of a few centimeters apart and stitches are placed alternatively through the vessel walls of the graft and the host. This distance between graft and host is technically less demanding in needle manipulation technique. After a few stitches both of these structures are approximated. Sometimes a knot is made at the start of an anastomosis to fix the most distant point.

Within a space of 1 to 2-cm it becomes very difficult to perform this parachuted technique and even more to start with a knot. The fingers that bring the knot down occlude all vision on the anastomotic site. In addition to the technical difficulty in a much reduced airspace, the parachuted technique might be inferior due to its potential “sawing” effect when approximating the graft to the coronary arteriotomy.

The most important element is the most distant heel of the anastomosis. A leakage is very difficult to repair without deforming the heel. Therefore we start with a very small U- or π-type stitch. Immediately thereafter the graft and host are approximated. The stitches are then placed without separating both components, making sure to address the walls in a perpendicular fashion and of course always from the inside towards the outside on the grafted vessel.

This method demands superior training in small space needle manipulation and rotation. This is trained extensively in low-fidelity simulation following a very strict curriculum of deconstructed movements and further facilitated by using 8-0 suture and needles of 6-mm length.
ANASTOMOSES TO THE PROXIMAL RIGHT CORONARY ARTERY
Coronary surgery to the proximal right has been the subject of considerable discussion and technical variability. In this section we will only discuss the elements appropriate to the OPCAB approach. It is understood at the start that there is a severe stenosis or occlusion of the RCA.

A number of components come into the technical equation. The right coronary vessel is often a very diffusely diseased vessel, with an internal diameter up to and sometimes greater than 3-mm. The right coronary artery perfuses a large part of the right and sometimes left ventricular muscular mass.

Temporary occlusion of the right coronary vessel can lead to complete atrioventricular block. For this reason a number of additional precautions and strict monitoring protocols are taken when the OPCAB approach requires a proximal right coronary anastomosis. We normally perform the proximal right anastomosis after grafting all other regions.

The anastomosis is often easier and with more visibility when performed from the left side of the patient. The suspension of the left pericardium is removed, this removal rotates the ventricle somewhat towards the left side of the chest. This rotation is further enhanced by suspending inferior and superior right-sided pericardium. The stabilizer is often placed on the left arm of the sternal retractor and points upwards or downwards according to the anastomotic site on the RCA. One pod of the stabilizer will be placed on the atrial wall and one pod on the right ventricular surface.

The conduction safety is improved by the placement before the start of this anastomosis of atrioventricular pacing wires and their testing. The ischemic safety is improved by placing the anastomosis at the end of the sequence when all other vessels have been grafted and opened. Shunting is strongly recommended (even in an occluded RCA) and therefore all the shunt sizes up to the largest caliber should be available in the operating theatre, including the 3-mm shunt.

The quality of the RCA vessel wall is often only visible after full stabilization and exploration. Therefore the deep stitch with the tourniquet (not the sponge) is left in place, because it could be that further exploration more distal on the RCA becomes mandatory, sometimes even demanding an anastomosis on the posterior descending artery. Maintaining the deep stitch and tourniquet facilitates the repeated exposure of the inferior surface of the heart.

THE ANASTOMOSIS TO AN INTRAMURAL OR INTRASEPTAL ARTERY
The anastomosis on the intraseptal pathway of the LAD on the moving and working heart is considered by many as pure hallucination. There is no magic or an exceptional demand of skills, but only a deconstruction of each step.

STEP 1
Study in depth the angiogram of the LAD and its side branches.

STEP 2
Identify on the patient anatomical identification points and determine the level of stenosis, for as far as possible.

STEP 3
Stabilize the region with a widened stabilizer and try having the LAD in the middle of the stabilizer, usually with the arm coming from the abdominal region.

STEP 4
Use a 15-blade knife and start feeling the exact position of the septal region by having a lateral movement of the knife over the epicardial surface.

STEP 5
Incise the epicardium according to the angiogram and above the position of the septum, over a distance of 2 to 3-cm and a depth of 3 to 4-mm.

STEP 6
Stabilize the region even more by bringing in an eyelid retractor with sharp points. This eyelid retractor has its joint towards the head of the patient (most frequently) and his branches bring in stability by spreading the septum and trying to find stability under the suction pods.

STEP 7
Continue the dissection by moving the 15-blade knife over the surface of the septum and gradually go deeper and deeper.
STEP 8
Try to keep a meticulous dry field.

STEP 9
Through gradual dissection one will start feeling the LAD or see part of it. The dissection is continued using visual recognition. Notice the rather complex stabilization of the whole area.

STEP 10
When perfect stabilization and visualization is obtained, then we can proceed with the incision. No controlling suture is placed proximally or distally since it is impossible to know if the vessels dive deeper into the septum or not.

STEP 11
The first assistant uses a very small dot-type sponge to control the LAD by pushing on the vessel proximally.

STEP 12
Incise the LAD 2-mm above the area where it is visible and make a 2-mm cut upwards with a cataract-type knife.

STEP 13
Incise the LAD upwards with a Potts scissor to obtain an appropriate incision length of 6 to 7-mm.

STEP 14
Place a rather large shunt upwards as far as possible. Usually at least 2-mm or more in shunt size. When the shunt is completely inserted, pull on the thread and keep the tip inwards of the coronary vessel in the downwards movement.

STEP 15
If insufficient hemostasis is obtained, go immediately for a larger shunt. Do not try to make an anastomosis in the septum with a leaking shunt.

STEP 16
Proceed with the anastomosis. Remember that a smaller needle has a smaller rotating arc and is therefore easier to use.
13.0 A MULTIFACTORIAL APPROACH TO AVOID STROKE

Stroke is a dramatic complication, annihilating through the loss of quality of life, the possible benefit of surgery.

Stroke as pathology is strongly associated with coronary artery disease. Therefore the coronary artery bypass patient is at risk for stroke during his complete further life. This risk increases gradually with the increase of the interval after surgery. However, the highest risk of stroke in the life of a patient with coronary artery disease is around surgery, more precisely the first 15 days after time 0, the start of surgery.\(^1\)

We had been monitoring stroke very strictly since 1971 and observed an annual rate of around 1.5%, after a thorough neurological investigation of every single patient who had any neurological symptom as well during the surgical stay as during follow-up.

Our efforts to reduce stroke were focused on the following:

- No more partial clamping of the aorta for cannulation and de-cannulation, as long as we were using extracorporeal circulation.
- Strict avoidance of partial and total clamping in the presence of aortic pathology, as identified on the coronary angiogram or during preoperative TEE (routine observations in all patients).
- A gradual decrease of partial aortic clamping in all patients through extensive sequential grafting.

These steps maintained our hazard of stroke around the 1.5% rate for the first 15 days, even with the increase of the risk variability as in older patients with more cerebrovascular disease. At the start of our OPCAB experience in 1997, we continued to partially clamp the aorta and hoped to annihilate stroke. After 3200 consecutive OPCAB patients, we observed the following elements (Figure to right):

1. The stroke rate had halved, just by going from on-pump to OPCAB mode. It now reached 0.7%.
2. The hazard function indicated a much lower prevalence in the first 2 days but a constant “noise” of risk extending for several days.

3. Additional steps were needed, beyond just using an OPCAB approach; therefore we were able to reduce the prevalence of stroke to an extremely rare event in thousands of patients.

These steps were focused on:

- The atherosclerotic disease of the aorta and carotid arteries
- The consequences of new onset of atrial fibrillation

We therefore decided to take a full-frontal attack towards stroke reduction by using a multifactorial approach.

**ISOLATED CABG\(^1\)**
(excl acute same day infarcts)
MULTIFACTORAL STEPS TO AVOIDING STROKE

STEP 1
Avoid by any means all contact with the aorta through the OPCAB mode and extensive (preferentially arterial) sequential grafting.

STEP 2
Reduce the combined CABG-carotid surgery to the patients with real neurological instability (very rare); increase the mean pressure of the patient in the patients with occluded or severely stenosed internal carotid arteries.

STEP 3
Create the most stable possible hemodynamic situation during OPCAB surgery, with strict avoidance of even PVCs and very slow manipulation of all cardiac displacements. Communicate with anesthesia and annihilate the need for conversion.

STEP 4
Protect the patient during his complete period of hyper-coagulopathy (the first 5 to 7 days) with therapeutic levels of anti-aggregation.

STEP 5
Protect the patient with therapeutic levels of anti-aggregation during the complete hazard phase of atrial fibrillation (up to day 7 at least); prolong this interval if atrial fibrillation has happened during the early phase; even ligate (if needed) every left atrial appendage. Our experience in several thousand consecutive patients, even with lower ejection fraction, has not shown any negative consequences on cardiac output or volume control.

CLOSING THOUGHT

This Procedure Guide and its special section Implementing OPCAB, have endeavored to capture the countless contributions from all of those who have shared in this journey of going from on-pump to a fully standardized OPCAB process. We hope you found this effort to be inclusive and informational — and to benefit of your patients.
Medtronic and Professor Paul Sergeant recognize that the learning and performance of OPCAB procedures vary. This special section represents the experience of Prof. Paul Sergeant. Medtronic does not endorse a single method of education or performance of OPCAB, however Medtronic appreciates the author’s vast experience in this area of cardiac surgery, including: research, peer reviewed publications, training and clinical experience in the expertise of CABG and OPCAB, for over 30 years.
IMPLEMENTING OPCAB — UNDERSTANDING THE ISSUES AND LEARNING CURVE

GENERIC ISSUE
Success or failure of the implementation of a new technology, such as OPCAB, is based on many interaction drivers.

SUCCESS OR FAILURE

<table>
<thead>
<tr>
<th>Completeness of Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate Learning Process</td>
</tr>
<tr>
<td>Enabling Material Provided</td>
</tr>
<tr>
<td>One-Time or Continued Proctoring</td>
</tr>
<tr>
<td>Auditing Process</td>
</tr>
<tr>
<td>Technological Push and Pull</td>
</tr>
<tr>
<td>Real World Events</td>
</tr>
<tr>
<td>Evidence</td>
</tr>
<tr>
<td>Efforts or Benefits of Implementing</td>
</tr>
<tr>
<td>Organization and the Safety Cocoon</td>
</tr>
</tbody>
</table>

EVIDENCE ISSUE
Evidence on OPCAB surgery has been very confusing. The data originating from experienced centers seemed always more convincing versus those coming from lesser experienced ones. The core issue has been that OPCAB was never proposed as a strict set of rules, procedures and training process. OPCAB was perceived as a menu wherein components could be chosen and deleted at will. This precluded that multi-center randomized control trials and meta-analyses were combining different concepts with different levels of safety monitoring, different anticoagulation and stabilization protocols, different levels of training, implementation and experience. It is obvious that evidence generated in such an environment would and always will be unstable.

Completeness of revascularization is a concept that has changed over time with a better understanding of competition of flow with the primary circulation and with other grafts. The degree of stenosis can now be measured in dynamic functional numerical terms versus previous visual two-dimensional estimation techniques. The completeness of revascularization should not be dependent upon the surgical approach. The observations made in several OPCAB studies of this variability in completeness should therefore only be based on incomplete concepts, training or experience.¹⁴
THE LEARNING CURVE ISSUE (I)
The prevalence of learning curves is often cited as the cause of failure for new approaches or procedures. However, learning curves take different shapes.

A first possible shape is the abrupt increase of the performance, from day one, from the previous level of performance up to the new level of performance. This is possible but will demand massive preparation and simulation training, possible but an atypical reality in the medical Profession.

THE LEARNING CURVE ISSUE (II)
A second possible shape shows, from day one, first a decrease in performance from the previous level, followed by a gradual increase of performance to a higher level versus the starting level. This shape of learning curve is the most common. From a medical ethics perspective this learning curve shape is not acceptable for the surgeon’s first OPCAB patients.
THE LEARNING CURVE ISSUE (III)
The acceptable learning curve for the patient is a third shape, where from day one a gradual increase of performance is observed. The science of learning has defined that this curve can only be obtained in the presence of an optimal conceptual and operational learning process. Such a curve is often asymptotic in shape. The objectives of this document are to obtain this last learning curve in the implementation process.

THE CONCEPTUAL LEARNING ISSUE
Operational learning is always preceded by conceptual learning. Conceptual learning mandates the formal creational process, by the team players, of a concept of work: a very detailed, complete and stepwise description of patient selection, materials, processes and interfaces during the OPCAB procedure. This can be based on existing concepts but it needs to be created by the team. The team consists of the four major players in this procedure: anesthesia, surgery, perfusion and nursing. The concept of work should also include all the possible tactical decisions in the presence of observations including the conversion and beyond. An optimal approach to OPCAB implementation involves the collegial interaction with interventional cardiology from the very beginning. Their understanding of changes of surgical strategy will optimize the differential therapeutic approach for the patient.

THE OPERATIONAL LEARNING ISSUE
The start of any quality circle is the availability of center-specific parameters that demonstrate completeness of revascularization.

The next step is the formal debriefing of the procedure by the core players anesthesia, surgery, perfusion and nursing staffs, followed by the data registration of the same parameters on the OPCAB patients. All this precedes the closure of the quality control circle. This operational learning makes the OPCAB therapeutic option sustainable in real practice.

<table>
<thead>
<tr>
<th>PARAMETERS TO MEASURE</th>
<th>ON-PUMP CABG CASES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENZYMATIC RELEASE</td>
<td></td>
</tr>
<tr>
<td>INCIDENCE OF STROKE</td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td></td>
</tr>
<tr>
<td>LENGTH OF HOSPITAL STAY</td>
<td></td>
</tr>
<tr>
<td>3-MONTH DATA</td>
<td></td>
</tr>
<tr>
<td>LATE OUTCOME DATA</td>
<td></td>
</tr>
</tbody>
</table>
**THE CONVERSION ISSUE**

The essence of the implementation of a new technology is the absence of the obligation to return to the previous technology, certainly if this return is associated with an increase in risk or cost (patient, hospital, insurance) as in OPCAB. The published conversion rates in OPCAB vary from 2 to 30%.

We consider every conversion a failure of either concept or of application of this concept. Every conversion should be debriefed and should lead to an improvement of the concept or to an enforcement of the implementation process.

The definitions for conversions, in clinical literature, are most frequently not given or vary. A conversion is identified only if a procedure has already started, unless the procedure is performed in an intention-to-treat study environment. Again, in OPCAB, this could mean after the start of anesthesia, after the sternotomy, after opening the pericardium or after the start of the anastomotic interval. In its strictest definition, any change of strategy, after the start of the first anastomosis and before the end of the last anastomosis, is most certainly a conversion. In this strictest definition it is essential for a successful implementation to have an improved conversion rate versus the previous method.

**SOLVING THE LEARNING EQUATION**

As stated before, the negative learning curve in the implementation process can be avoided through the creation of a strict concept and crew resource management, but more will be needed from the surgeon. An anastomosis in an angulated and reduced airspace with a moving target demands different anastomotic techniques and different surgical skills. These skills may be learned in low-fidelity simulators until a repeatable perfect Objective Structured Assessment of Technical Skills (OSATS) -based score is obtained. Many teams, in my observation, have only implemented an OPCAB approach for single vessel revascularization on the anterior wall or for multi-vessel revascularization in the presence of calcified aortas or of considerable co-morbidity.
For more information, contact your local Medtronic Products Representative.
U.S. Customer Service: (800) 328-1357.

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.