Introduction
Since its reintroduction in the late nineties, the acceptance of the OPCAB surgery by the cardiovascular community has varied between 1% to 98% [1,2]. This large variability clearly reflects an incredible disparity in the acceptance of the procedure. The group from Leipzig initially proposed a series of indication regarding the procedure [3]. With time others have encourage a more liberal use of off-pump surgery [4]. Nevertheless it appears that the limiting factor remains the surgeon's experience. The main indication for going off-pump is to decrease the inherent morbidity related to the use of the CPB especially among patients with significant comorbid factors. Other indications are clotting disturbance, calcified aorta, and minimization of blood transfusion. But down the road the final decision will be taken according to the coronary anatomy, the size of the myocardium, and the tolerance of the patient's hemodynamic to surgical mobilizations and manipulations. Table I and II displayed the major and relative contraindications to OPCAB surgery that we have followed throughout our seven-year experience (and close to 950 cases) with the technique. The purpose of this chapter will be to review the different surgical strategies that we have progressively developed to optimize the OPCAB procedure.

<table>
<thead>
<tr>
<th>TABLE 1. Contraindications to OPCAB surgery.</th>
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<tr>
<td><strong>Absolute:</strong></td>
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<td>- Preoperative hemodynamic instability.</td>
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<td>- Deep myocardial Left anterior descending artery.</td>
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<td>- Moderate (3+) or severe (4+) mitral insufficiency</td>
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<td><strong>Relative:</strong></td>
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<td>- Pulmonary hypertension</td>
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<td>- Diffuse coronary artery disease</td>
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<td>- Dense myocardial adhesion during reoperative surgery</td>
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<td>- Enlarge ascending aorta</td>
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<td>- Left main disease with a non-reconstructable right coronary network</td>
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Approaching the LAD and Diagonal
The left anterior descending artery is the easiest target to reach. Being located on the anterior face of the heart minimal surgical mobilization is required. Although a simple sponge located behind the heart is necessary to move the apex in the surgical field we have opted through the years to a "single" stitch approach (Figure 1). The free edge of the left side of the pericardium is hold and lifted up by the assistant as the operator anchors a single stitch just above the phrenic nerve where the apex of the heart normally lay down. This brings the apex of the myocardium straight in the mid line and has the advantage of being stable throughout the suturing period contrary to sponges that get progressively wet and loose volume necessitating once in while a repositioning by the surgeon. The diagonal artery (DA) is generally approach the same way but sometimes necessitates a second stitch close to the left pulmonary inferior pulmonary vein to create more rotation and facilitate access. The table is generally rotated 20 degrees towards the surgeon with a slight Trendelenburg positioning.
Special care should be taken with the positioning of the stabilizer on the DA (as mentioned in chapter VIII). The DA crosses the path of the left ventricular outflow tract. Any significant deformation of the funnel shape of the tract will create obstruction and increase to after load of the LV (Figure 2). The LAD running on top of the septum has less compromising effect during stabilization.

Figure 1: The single stich approach for exposing the LAD artery.
Approaching the PDA
The posterior descending artery is approached in a similar fashion. The apex is brought in the mid-line as described with the LAD. The table is set in a 30-degree "head down" position and tilted 30 degrees away from the right-sided operator. The closest to the base of the heart the target vessel is, the easier the coronary stabilization will be. When the mid-PDA is targeted for anatomical reasons the oscillation of the apex frequently impedes a satisfactory stabilization. The use of an apical suction, in these circumstances, contributes to enhance the stabilization (Figure 3).

Approaching the RC (Video 1)
With the LAD the RC artery is the target vessel that requires minimal surgical manipulation. In order to bring the surgical target in the middle of the surgical field two pericardial stitches are anchored, one just above the inferior vena cava (IVC) and the other in the same plane just above the left atrium. The table is rotated 20 degrees opposite to the operator with a 20-30 degree head-down tilt positioning. This brings the mid-RCA straight on the mid-line and really eases the positioning of the stabilizer.

Approaching the OM (Video 2)
Exposure of the circumflex territory has been topics described before [5]. We developed this approach in 1996, which consist in 4 deep pericardial stitches ranging between the left superior pulmonary vein and the inferior vena cava. This technique is quite comparable to the "Lima Stitches" introduced in North America in 1997 by Tom Salerno [6]. Although some warning [7] about the risk of retro- mediastinal bleeding with those deep pericardial stitches have been voiced, our experience, close to 1000 cases, has been free of severe complication. We do express some concern though about how deep these stitches should be inserted. The lungs should be deflated first. Then the assistant has to pull the free edge of the pericardium and kept it under tension with his left hand while with his right hand holding the wall suction retracts the pericardium. This generously enhances the vision field of the operator.

Obviously care has to be taken not anchored to deep those stitches especially toward the pleural space. We have encountered once in a while a persistent left pneumothorax. We now routinely leave the left chest tube in place for a minimum of 48 hours; beyond this delay it is generally safe to remove the chest tube. The four stitches are superficial and located close to the heart at just about 2 centimetres away from the pericardial reflection. The surgeon has to pass the needle of the pericardial suture away from the heart and not towards it to avoid any risk of myocardial injury. The first suture is anchored just above the left superior pulmonary vein, the second below the left inferior pulmonary vein, the third one call "the intermediate" is located between the inferior pulmonary vein and the inferior vena cava, and the fourth one close to the inferior vena cava (Figure 4). Once completed this generally provide a complete virtualization of the heart. This allows the surgeon to...
position the stabilizer without touching the heart with minimal hemodynamic disturbance. Because all the coronary arteries converge towards the apex, by controlling the apex the operator has theoretically access to all of them (Figure 5).

**Figure 4:** Schematic showing the positioning of the four deep pericardial traction stitches spreading from the left superior pulmonary vein (LSPV) to the inferior vena cava (IVC)

**Figure 5:** Surgeon's view of the posterior wall.

**The coronary anastomosis**

The suturing technique that we use is similar to what we were familiar with conventional on-pump surgery. This generally consists to “parachuting” 3 or 4 suspended stitches before completing the running suture. Polypropylene 7-0 or 8-0 sutures are used for ITA grafting (sequential and distal) according to the size of the distal vessels. Bloodless field is obtained by gentle snaring of the target coronary artery with silicone vessel loops. Proximally, the loops are crossed over whereas distally a single looping is used to avoid damaging the distal bed (Figure 6). The tension is kept minimal distally by fixing the tension directly on the stabilizer (CorVasc, CoroNéo, Montreal, Canada), which allows a better control the applied tension. Lately, some
authors have advocated the systematic use of shunts during the grafting period [8]. Numerous publications have expressed concerns on the effect of shunts on the coronary artery endothelium function [9-11]. Although it has been shown experimentally that decreasing the size of the shunt could attenuate the endothelial damage, significant endothelial damage still persists. At the opposite silicon loops have been shown to create minimal injury to the endothelium compared to polypropylene snaring or endovascular shunt [12]. We prefer to use shunts only in specific circumstances, which will be discussed later.

Once the graft anastomosis is completed the patency is verified with the Doppler probe (Smartdop, Hadeco). On the left coronary network we pay a special attention to the importance of the diastolic velocity (>0.8KHz) and the ratio of diastolic to systolic velocity ratio (2 or more). We do not hesitate to refashion the anastomosis if there is any doubt on the graft patency (up to 8-10% in our practice). On the right coronary network we look for equalization of the systolic-diastolic ratio, the right coronary artery gets half of its blood flow during systole.

Surgical Strategies (Table II)

One of the goals sought for by the surgeon during the OPCAB surgery is obviously to avoid CPB conversion. In order to minimize the risk of myocardial ischemia during coronary manipulation and grafting, we have established and followed, early on, these following rules. First, the most stenotic vessel is always revascularized first. This vessel is normally well collateralized and support occlusion without threatening myocardial ischemia. Second, when a saphenous vein or a radial artery conduit is used the proximal anastomosis is completed once the distal anastomosis is completed, before the next distal anastomosis. The ante-grade flow will provide, through the collaterals, supportive blood flow during the next coronary cross clamping. Normally the right or the LAD artery is revascularized first. Third, we generally perform a pre-ischemic test of 2 minutes before grafting the LAD especially when the stenosis is not critical. Shunts are used only when ischemia is suspected. Forth, the ascending aorta is side-clamp only once during the procedure to minimize the aortic trauma. Fifth, the systemic pressure is always reduced around 90-100 mmHg before and during the entire side clamping of the ascending aorta. Sixth, the anterior and the inferior territories are always grafted before the posterior territory.

### Table 2. Surgical strategies during OPCAB surgery.

| 1) | "Culprit lesion first" |
| 2) | Antegrade flow established before second anastomosis |
| 3) | Preischemic test prior to LAD grafting |
| 4) | Single side clamping of the ascending aorta |
| 5) | Moderate hypotension during proximal anastomosis |
| 6) | Revascularization of the anterior and inferior territories prior to the circumflex artery |

**Special situations:**

- **Dealing with the big heart**

The dilated ischemic cardiomyopathy is, without any doubt, the most difficult case to expose during OPCAB surgery. In these circumstances the working space between the posterior wall of the heart and the left arm of the retractor is reduced. In order to increase this working space a large opening of the right pleural space could be made or a separation of the diaphragmatic and pleural pericardium. Through the years we have adopted the last one. This "pleuro-diaphragmatic disconnection" is normally carried out with the electrocauterizer at moderate power to avoid injuring the phrenic nerve. It could be further extended toward the inferior pulmonary vein. This will deepen the base of the heart and facilitate the work of the surgeon by...
opening up the working angle on the posterior wall. (Figure 7a-b).

**Reoperative surgery**

A frequent situation in reoperative surgery is the presence of an occluded native coronary artery whose vascular supply depends of a severely stenotic graft, which is frequently the LAD (Figure 8). Commonly, the diseased graft has the culprit lesion and is responsible for the recurrent angina the patient is complaining about. Manipulation of this graft has to be carried out with gentleness to avoid any worsening of the ischemia and potential hemodynamic instability. The easiest way to deal with this situation is to revascularize with an "in-situ" arterial bypass such as a left or a right internal thoracic artery. This will avoid the side clamping the ascending aorta and a further exacerbation of ischemia in the dependent territory. If only one ITA is available or if no ITA is available at all the surgeon has to plan out in advance be prepared for "Tector" setting with either a radial artery or a saphenous vein or use the brachiocephalic trunk for proximal anastomosis. Both subclavian arteries should preferably be scanned prior to surgery with special attention paid to the brachiocephalic artery that could be used as a donor artery. Other alternatives are the new aortic connectors allowing proximal anastomosis without side clamping.

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**Figure 7A:** The "pleuro-diaphragmatic disconnection" use to increase the working space.

**Figure 7B:** The deepenening of the base of the heart increases the working space on the posterior wall.
The calcified ascending aorta

With a constantly aging surgical population, assessment of the ascending aorta prior to side clamping has become a necessity. Lately we have routinely adopted in patients aged 75 years and older the epiaortic scanning of the ascending aorta using a 17 MHz probe (Figure 9). This has lead us once in a while to a different strategy of revascularization notably a more aggressive use of the "no-touch" technique, which appear to has been beneficial on the neurological outcome [13].
- The sudden pulmonary artery pressure raise
Occasionally, due to surgical manipulations or more frequently to myocardial ischemia the pulmonary artery pressure suddenly rises above normal during the procedure. This is generally followed by left ventricular distention and unstable hemodynamic. This is a potential life threatening condition that is related to sudden ischemic mitral insufficiency. In order to reestablish the patient's hemodynamic and avoid acute conversion to CPB the inferior vena cava is temporary cross-clamped or progressively snared. By decreasing the inflow the LV rapidly shrinks, which instantly restores its contractility. This could be tolerated for few minutes before the occlusion is relieved progressively. The effect of this manoeuvre is the comparable of a bolus of intravenous nitro-glycerine. We have practiced it in close to 10% of all our cases with no long-term side effect [14].

Blood saving
One of the major advantage of the off-pump approach has been the reduce blood loss and transfusion need during and after the procedure. This has been reported by a majority of authors. In our experience, avoiding the cardiopulmonary bypass apparatus has cut down by more than a half the incidence of blood product transfusion [15]. This went from 62% “on-pump” to 21% in our latest experience. This is due to our strict guidelines about blood recovery and transfusion policy. Currently, we recover the shed blood in every case. When the blood losses remain below 400 ml the blood is directly reinfused to the patient (Figure 10a). When it goes beyond 400 ml the blood is purified and concentrated in a self-saver (Figure 10b). In the postoperative period we also partially recover the shed blood but generally the amount of re-infused blood is kept under 5-7 ml/Kg.

Figure 9: Epiaotic scanning od the ascending aorta.
Use of Aprotinin

The use of aprotinin has been shown efficient in reducing blood loss in coronary artery surgery with and without cardiopulmonary bypass [16]. A recent randomized trial has further confirmed its effectiveness in OPCAB surgery in regard to blood loss and perioperative transfusion [17]. Others, however, have reported deleterious prothrombotic effect of the drug on graft patency and have given off a word of caution on its use [18]. In our series, aprotinin has been administered to 32 OPCAB patients during the last 3 years. These were...
patients on antiplatelet drugs prior to surgery. No operative death was reported. Only one patient sustained a delayed stroke that occurred 10 days later after undergoing a femoral angioplasty following a BIA withdrawal. This patient had a previous aortobifemoral bypass. None sustained a perioperative myocardial infarction and at 30 days post surgery no venous thromboembolic complication was reported. Prevalence of transfusion was 25%. Although such a short series does not allow drawing any strong conclusions on the efficacy of aprotinin to reduce blood loss it surely confirms its safety at short-term (up to 30 days) follow-up. This is an important aspect because a postoperative hypercoagulable state has been suggested following OPCAB [19], which could be further amplified by the use of aprotinin [20]. We do not use it on a routine basis but only in patients with clotting disturbances on whom excessive bleeding is expected.

Conclusion
This was a brief overview of the technique we developed over the last seven years that lead us to achieve systematic off-pump surgery in close 98% of our case load. Obviously each surgeon has to develop his own approach and be comfortable with. We have opted early in our experience for reusable stabilizers for their low cost. We remained faithful to the same technique of verticalisation through the years because it was simple, reliable, inexpensive, and easy to teach. We learned how to deal with special situations and avoid precipitous conversion that could sometimes be life threatening for the patient [21-22]. Our rate of conversion has remained low (less than 0.5%) with a rate of complete revascularization above 90%. We believe that this could be use as a guide for any surgeon not familiar with the technique but anxious to learn how to get comfortable with.

References
