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# Current Trend of Off-Pump Coronary Artery Bypass Grafting

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## 1. Introduction

Coronary artery bypass grafting (CABG) using cardiopulmonary bypass (CPB) and cardioplegic arrest has been performed safely over several decades. Cardiac surgery under cardiac arrest provides a bloodless stable operative field, that can facilitate anastomosis. In last decade, CABG without CPB, off-pump CABG (OPCAB) has become more common with advances in surgical instruments and technique. This chapter summarizes the surgical technique, risks and benefits of OPCAB.

## 2. Technical aspects

### 2.1 Anesthesia

After standard sternotomy and appropriate graft harvesting, a pericardial well is created. A standard dose of heparin is administered by the anaesthesiologist. The anaesthesia team should be prepared to perform appropriate hemodynamic monitoring. We use transesophageal echocardiography and Swan-Gantz catheters to monitor cardiac function in all patients. Activated clotting time above 350 is sufficient to perform OPCAB; however, a full dose of heparin may be given in cases undergoing emergent conversion to CABG using CPB. The anaesthesiologist should inform the surgical team any abrupt decrease in blood pressure, ST changes on EKG and arrhythmia, because these are signs for possible emergent conversion to CPB.

### 2.2 Retropericardial suture

The patient is placed in the Trendelenburg position and the sternal retractor is open widely. Right side stitches holding the pericardial well are released to minimize compression of the right heart. While the apex of the heart is gently elevated using one hand, retropericardial sutures are placed to support the heart (Figure 1). To minimize hemodynamic instability, we place the first retropericardial stitch into the mid-portion of the diaphragm. The stitch is pulled out to the right side of the lower edge of the skin incision and tightly secured so that the heart is somewhat elevated. The second deep pericardial stitch is applied to the midportion between the inferior vena cava and the left lower pulmonary vein, and the stitch is passed though a rubber catheter so that the heart will not be injured by the retropericardial sutures.

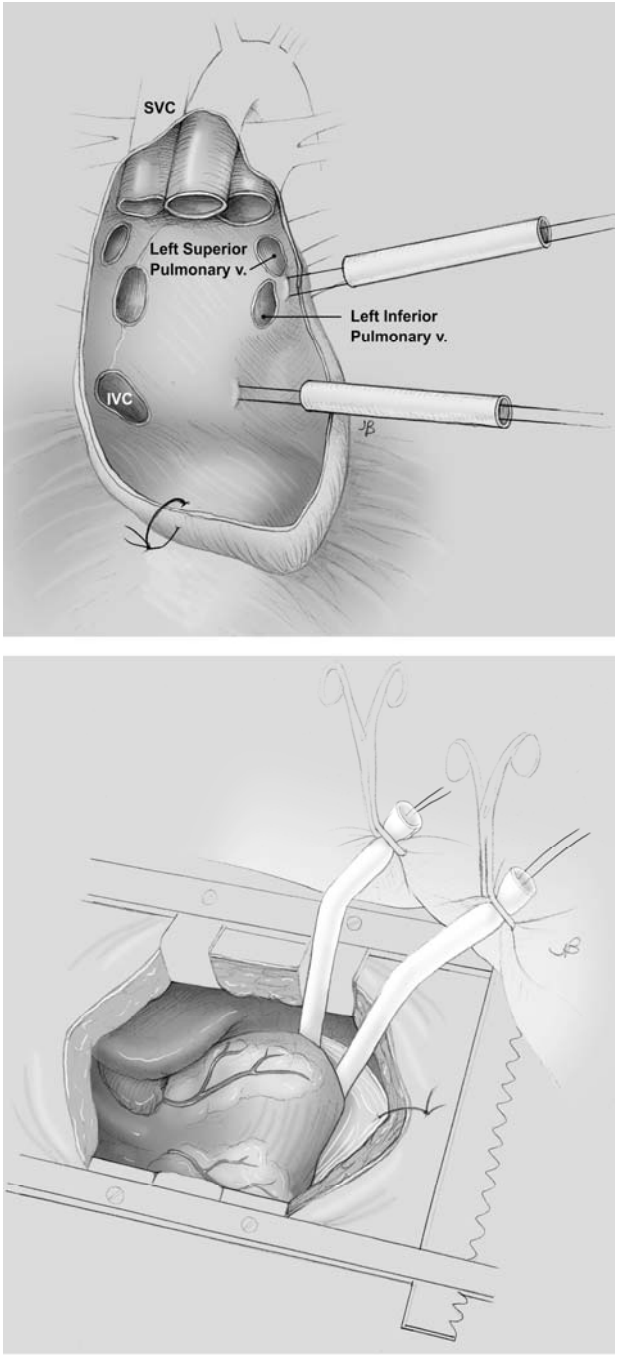


Fig. 1. A model of retropericardial suture.

The third stitch is applied inferior to the left upper pulmonary vein and is also passed through a rubber catheter. Usually three retropericardial sutures are sufficient to support the heart; however, an additional retropericardial suture can be added between the last two retropericardial sutures. An abrupt drop in blood pressure may occur during retropericardial suture placement. This hemodynamics instability is usually transient and injection of a small dose of vasoconstrictor or volume management will be enough to regain blood pressure. ST segment changes on EKG during the heart displacement is often observed in patients with severe left main disease. Preoperative intra-aortic balloon pump (IABP) placement would be helpful to maintain hemodynamic stability. If there is a persistent drop in blood pressure, ST-segment changes, and/or ventricular arrhythmia occurs during the manipulation of the heart, it is an indication to abort the OPCAB and convert to on-pump CABG. If the patient is not tolerating the short period of heart displacement during retropericardial suture placement, the patient most likely would not tolerate a longer period of heart displacement while performing anastomoses. Some surgeons may use suction-cup device to place the heart in an appropriate position. The use of a suction cup device and the use of retropericardial sutures have been proven to have similar effects (Gunnert et al., 2008).

### 2.3 Anterior wall revascularization

Anastomosis to the left anterior descending artery (LAD) using the internal mammary artery (IMA) graft is key to the success of OPCAB so that the LAD can be perfused after anastomosis. Without the Trendelenburg position, minimal elevation of the left heart with one or two sponges is usually sufficient to approach to the LAD. If the right ventricle is compressed and venous return is decreased, a significant decrease in blood pressure can occur. To avoid stress on the right system, the right pleura may be opened. This allows the heart to herniate into the right pleural space during heart displacement and minimizes the hemodynamic compromise.. After exposure of the target vessel, a suction type coronary stabilizer is placed on the target vessel. Before making coronary arteriotomy, a proximal snare is placed to the coronary artery slightly proximal to the anastomosis area using a silicone suture (Figure 2 top). EKG and blood pressure are carefully monitored by anesthesiologists. An arteriotomy is made on the target. Then a intracoronary shunt is quickly inserted into the coronary artery (Figure 2 middle) and the proximal snare is released (Figure 3 bottom) (Emmiler et al., 2008).

The sizing of the shunt is important. If a larger shunt is selected relative to the coronary artery size, the surgeon may encounter difficulty in placing the shunt into the coronary artery; moreover, vigorous forceful insertion of the shunt may cause injury or local dissection of the coronary artery. On the contrary, if a smaller shunt relative to the coronary artery is selected, the surgeon may experience excessive amount of bleeding from the anastomosis site, and smaller shunt may not able to supply enough blood distally. A CO2 mister-blower helps to provide a bloodless operative field. Anastomosis is performed in the standard manner; however additional care is always taken not to place a suture into the shunt. Right before completion of the anastomosis the proximal snare is tightened, the shunt is removed, and then the sutures are tied. Removal of the proximal snare allows abrupt restoration of distal coronary flow. In some cases of a small target coronary artery, the anastomosis can be performed without a shunt using a proximal snare only. If the target vessel is totally occluded vessel, the proximal snare is not necessary because of lack of forward blood flow. The IMA flow should be checked with ultrasound doppler before posterior or inferior wall revascularization.

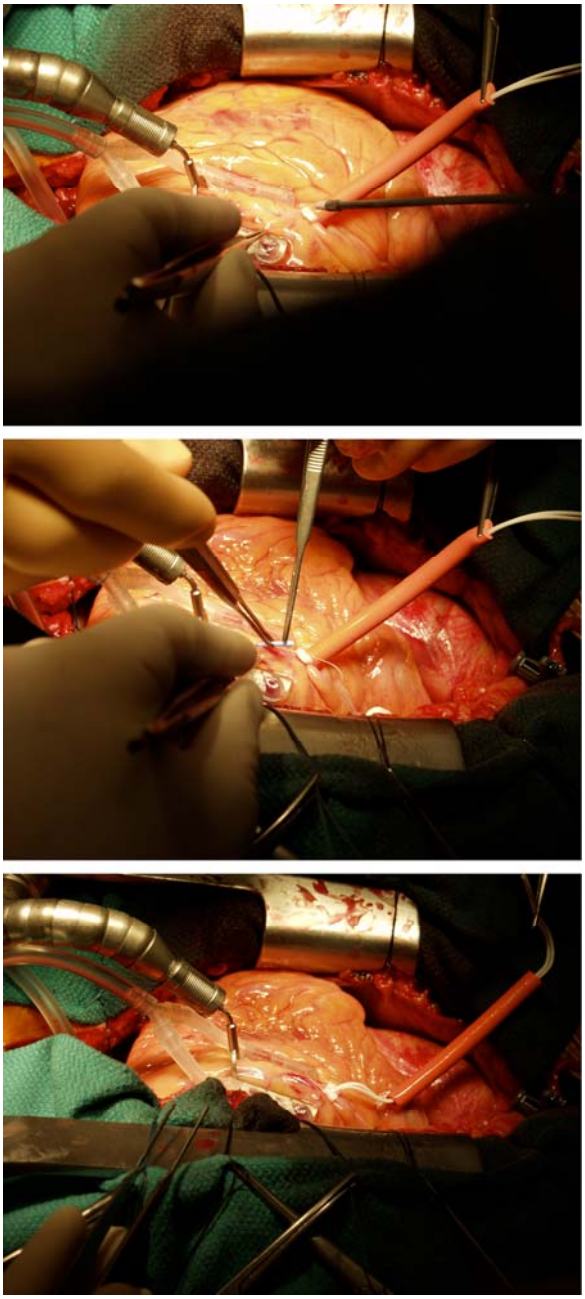

Fig. 2. Suction stabilizer and proximal snare is placed on to the target vessel (top). A shunt tube is placed thought the arteriotomy (middle). Proximal snare is open after shunt tube placement and the coronary vessel is ready to anastomose (bottom)

### 2.4 Posterior and inferior wall revascularization

After IMA-LAD anastomosis, anastomoses to the obtuse marginal branch (OM) or posterior descending artery can be performed. Prior to the OM anastomosis, the patient is placed in a steep Trendelenburg and left side up position on the operating table. The heart is gently elevated using a hand and then the heart can be rested on the retropericardial sutures. If the blood pressure drops, the heart is placed back into the natural position and wait for recovery. The previous IMA-LAD graft should stay open and this IMA-LAD flow will help the hemodynamics during the OM anastomosis is completed. Phenylephrine is a first drug of choice for hypotension during the anastomosis, because phenylephrine increase blood pressure without causing tachycardia. If persistent hypotension occurs, conversion to on-pump should be considered. However, we found most of patient with normal left ventricular function will tolerate displacement of the heart during the anastomoses. After adequate exposure of the target vessel, a stabilizer is placed onto the target. Confirmation of stable hemodynamics is necessary prior to making an arteriotomy. In a sequential manner, proximal snare placement, arteriotomy, shunt placement, release of the proximal snare, and then anastomosis are performed. Arterial blood drawn by the anesthetist should be avoided during the anastomosis of the posterior wall. After the OM anastomosis, the position of the operating table is returned to zero and maintain the Trendelenburg position. Anastomosis to the inferior wall is performed in a similar manner.

### 2.5 Proximal anastomosis

Proximal anastomoses are performed after all distal anastomoses. The patient is placed in a slight reverse Trendelenburg position, systolic blood pressure is controlled by anesthesia with a target of 110 mm Hg, so that the proximal clamp is not dislodged during the proximal anastomosis. Displacement of the proximal clamp during the proximal anastomosis is dangerous and may cause massive exsanguination, and may also cause aortic dissection. After achieving an adequate blood pressure, a side-biting clamp is gently applied to the ascending aorta. An aortotomy is made and proximal anastomosis is completed in the standard manner. The side-biting clamp is removed and the grafts are de-aired. Proximal anastomosis of the graft may be performed before the distal anastomosis, especially if a proximal automatic anastomosis device is used. The automatic proximal anastomosis device is useful for the patient with severe calcification of the aorta.

### 2.6 Doppler assessment to the grafts

After completion of all anastomoses, the blood flow of the grafts should be accessed using an ultrasound flow probe. A poor graft flow mandates additional attention to the anastomosis and consider revision of the graft anastomosis (Kim et al., 2005). Protamine is administered after confirmation of the graft flow and then the chest is closed in the standard manner.

### 2.7 Postoperative management

Without using CPB, the fibrinolytic activity of the patient who undergo OPCAB is lower than those who undergo conventional CABG using CPB. After OPCAB surgery, patient may develop a hypercoagulable state. To avoid platelet aggregation at the anastomosis site, clopidogrel is started as early as postoperative day 0 (Quigley et al, 2003). Other postoperative managements are similar to those after on-pump CABG.

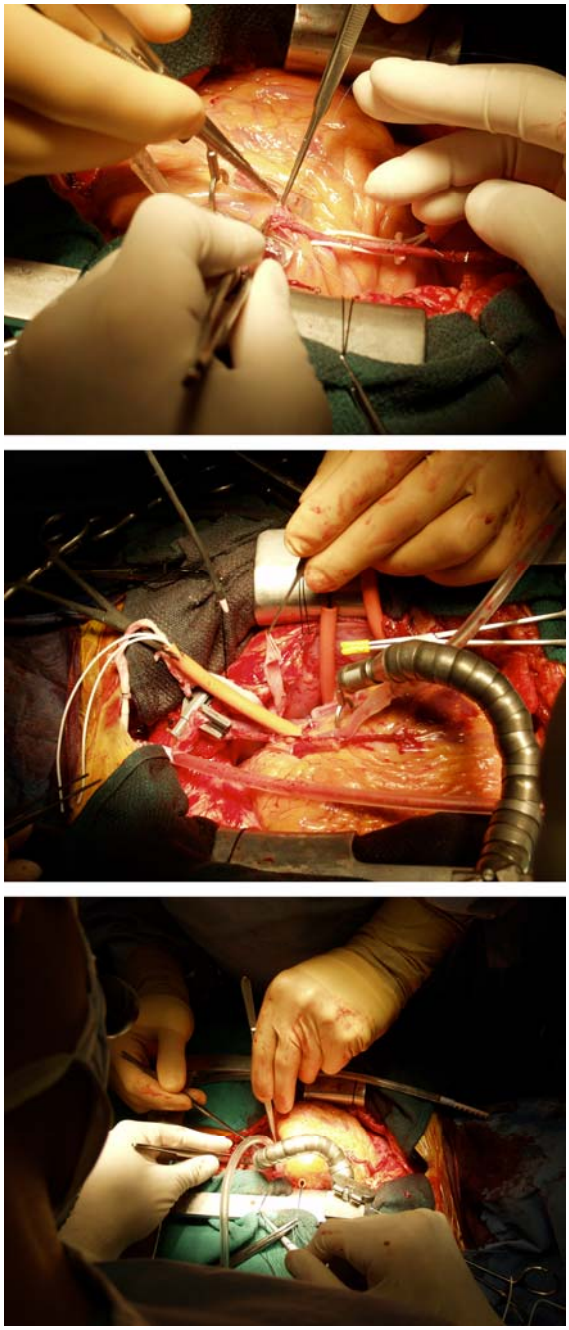

Fig. 3. Examples of anterior (top), posterolateral (middle), and inferior (bottom) revascularization.

## 3. Advantages of OPCAB

In general, those who are considered to be contraindicated for on-pump CABG, such as patients with calcified aorta, advanced age, and significant comorbidities, can be a candidate for OPCAB. OPCAB does not require CPB and theoretically eliminates all CBP-related complications. OPCAB can reduce blood loss and the need of transfusion. OPCAB has known to provide less myocardial enzyme release, fewer incidence of neurocognitive dysfunction and postoperative renal injury than conventional CABG. Studies found OPCAB can make patient recovery time shorter as well. Table 1 summarizes the best candidates for OPCAB.

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|---|
| Calcified aorta |
| Advanced age |
| Significant comorbidities |
| Recent stroke |
| Severe carotid disease |
| Renal dysfunction |
| Severer chronic lung disease |
| Jehovah's Witness |

Table 1. The patients that benefit most from CABG

### 3.1 Mortalities

Studies have shown that postoperative mortality is favorable to OPCAB (Puskas et al., 2003, Cleveland et al., 2001, Puskas et al., 2008). Mortality benefit from OPCAB is more obvious in high risk patients. (Hirose et al., 2010). The reasons are multifactorial as discussed below; however, the benefit most likely related to the avoidance of CPB.

### 3.2 Stroke

Postoperative strokes are the most disabling complication after CABG. Avoidance of aortic cannulation and aortic cross clamping decreases the risk of stroke and distal emboli. The incidence of postoperative stroke is favorable to OPCAB compared to on-pump CABG; however stroke has not been completely eliminated by OPCAB (Puskas et al., 2003, Cleveland et al., 2001, Sabik at al., 2002). The use of side-biting clamp for proximal anastomosis is potentially the cause of postoperative stroke. Calafiore reported that the stoke rate without using side-biting clamp was 0.2%, which was significantly lower than the stroke rate with side-biting clamp (1.2%) (Calafiore et al., 2002). All in-situ grafting using bilateral mammary arteries, gastroepiploic arteries and Y-composite grafting eliminates proximal aortic anastomoses. Using this aorta-non-touch surgery, theoretically no intraoperative stroke would occur and the postoperative risk of stroke should be minimal (Hirose et al., 2004). An investigation demonstrated that OPCAB significantly reduced the incidence of intraoperative stroke; however, the incidence of delayed strokes occurring more than 48 hours after OPCAB was similar to that after on-pump CABG (Nishiyama et al., 2009). These delayed strokes are not to be related to aortic manipulation during surgery, but could be related to a hypercoagulable state and/or postoperative atrial fibrillation.

### 3.3 Neurocongnitive dysfunction

Neurocongnitive disorder after CPB is a well known phenomenon, so called "pump head." Prolonged CPB time is a risk factor for postoperative neurocongnitive disorder, most likely related to non-pulsatile flow, hypothermia, low perfusion pressure, systemic inflammatory

state, and most importantly micro-emboli from CPB. Studies of s100 protein, a marker of neurological damage, have shown lowers s100 protein after OPCAB compared to those after on-pump CABG; however, the incidence of clinical neurocongnitive manifestation was similar between OPCAB and on-pump CABG (Lloyd et al., 2000). The benefit of OPCAB in relation to neurocongnitive disorder remains controversial (Van Dijk et al., 2002, Browne et al., 1999, Marasco et al., 2008).

### 3.4 Inflammatory reaction

Contact between the blood and the CPB circuit triggers an inflammatory cascade. Cytokines, complements and coagulation-fibrinolytic system are activated by CPB, which inducing CPB-related inflammatory responses (Ngaage, 2003). This inflammatory response contributes to the increase in capillary permeability, fluid shift, and decrease in tissue perfusion. Systemic inflammatory response syndrome may cause multi-organ failure, including lung, brain, kidney and heart, which may promote patient mortality. Significant decrease in inflammatory markers has been observed in OPCAB compared to that in on-pump CABG (Ascione et al., 2000). Avoidance of CBP reduces the inflammatory state and contributes to early patient recovery (Raga, 2004). CPB-related inflammatory response could cause pulmonary edema resulting in hypoxia, brain edema resulting in neurocognitive disorder, renal hypoperfusion resulting in acute renal failure, and edema of the heart resulting in low cardiac output syndrome.

### 3.5 Blood transfusion

Perioperative anaemia among the patient undergoing CABG is common. Hemodilution may occur from the circuit and tubing of the CPB. The use of CPB activate fibrinolytic activity and reduce the actual number of platelet and function of the platelet, which aggregates perioperative blood loss anaemia (Khuri et al., 1992). Studies have shown that OPCAB has clear benefits in blood preservation. Postoperative blood loss and transfusion requirements are smaller in OPCAB than in on-pump CABG in almost all studies (Muneretto et al., 2003). Avoiding the need for transfusion is critical in caring for Jehovah's Witness patients.

### 3.6 Renal function

Hypoperfusion of the kidney during CABG may cause postoperative renal dysfunction. Risk factors for renal dysfunction are often observed in patients who undergo CABG, such as patients with diabetes, hypertension and peripheral vascular disease. Non-pulsatile flow and low perfusion pressure due to CPB contribute to hypoperfusion of the kidney, causing postoperative kidney injury (Laffey et al., 2002). The duration of CPB has been known to be directly related to the incidence of postoperative renal failure. The postoperative rise in creatinine after OPCAB is less frequently observed than that after on-pump CABG (Celik et al., 2005). A lower incidence of postoperative renal failure is observed after OPCAB (Calafiore et al., 2003). This renal protection with OPCAB would be most beneficial for patients showing moderate or severe preoperative renal dysfunction (Hirose et al., 2001).

### 3.7 Respiratory function

A randomized trial showed that OPCAB provides lower pulmonary compliance, better gas exchange after surgery than on-pump CABG (Staton et al., 2005). Clinically, intubation time after surgery as shorter after OPCAB than after on-pump CABG (Puskas et al., 2008).

### 3.8 Atrial fibrillation

Atrial fibrillation is the most common arrhythmia after cardiac surgery and occurs in 25-40 % of patients. The incidence of atrial fibrillation after OPCAB is known to be less than that for on-pump CABG (Ascione et al., 2000, Raga et al., 2004). Avoiding atrial cannulation and preserving the anterior epiaortic fat pad may contribute to lowering the incidence of postoperative atrial fibrillation (Cummings et al., 2004).

### 3.9 Patient recovery

Due to the benefits listed above, OPCAB provides overall decreased postoperative complications and mortality (Puskas et al., 2008, Reston et al., 2003, Legare et al., 2004). Postoperative hospitalization is shorter in OPCAB patients than that in on-pump CABG (Puskas et al., 2003, Cleveland et al., 2001, Van Dijk et al., 2001). Earlier patient recovery in OPCAB could be related to reduced inflammatory reaction compared to that after on-pump CABG. The benefits of early recovery following OPCAB are more strongly apparent in high-risk patients (Stamou et al., 2005, Puskas et al., 2009).

### 3.10 Cost

The cost effectiveness of OPCAB can be explained by the reduced utilization of the blood products, shorter intubation time, shorter ICU stay, shorter hospitalization, and reduced postoperative complications, as described above (Scott et al., 2009, Puskas et al., 2004).

## 4. Potential problems and disadvantages of OPCAB

In general, the disadvantage of OPCAB is associated with surgical technique. Despite advances in surgical instruments, exposure of the posterior wall could be potentially difficult, especially in a patient with poor ventricular function or when the surgeon has not had adequate training in OPCAB. Inadequate exposure of the target results in fewer number of distal anastomoses and incomplete revascularization. Table 2 summaries poor candidates for OPCAB.

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| Cardiogenic shock |
| Unable to maintain hemodynamics during anastomosis |
| ST changes or ventricular tachycardia during anastomosis |
| Redo surgery |
| Poor ventricular function, ischemic mitral regurgitation |
| Poor coronary target |
| Small, intramyocardial, and/or calcified coronary artery |
| Young healthy patient |

Table 2. The patients that the benefit least from OPCAB

### 4.1 Myocardial protection

Postoperative cardiac enzyme release is lower after OPCAB than after on-pump CABG. (Van Dijk et al., 2001) However, in a patient in cardiogenic shock with a failing heart, placement on the CPB is unavoidable to prevent further end organ damage, and the role of OPCAB is limited because of hemodynamic instability. If the patient is experiencing global ischemia, pump failure and unstable hemodynamics, OPCAB should not be performed.

These patients need immediate placement on CPB to reestablish systemic circulation. Hemodynamic instability may occur during the positioning of the OPCAB especially doing anastomosis to the posterior wall of the heart. If pharmacological support is not adequate, IABP is helpful to maintain hemodynamic stability during OPCAB (Vohra & Dimitri, 2006). In patients with poor ventricular function, IAPB placement prior to surgery is recommended.

### 4.2 Redo cardiac surgery

Redo surgery requires extensive dissection of the scar tissue. Structural injury during redo-sternotomy will result in a high mortality and morbidity (Gillinov et al., 1999). Decompression of the heart by CPB is recommended for redo surgery (Hirose & Amano 2005).

### 4.3 Multivessel disease

In the early era of OPCAB, revascularization of the posterolateral wall was challenging. However, after improvement of the coronary stabilizer, anastomoses to the posterolateral vessels are no longer a contraindication (Hirose et al., 2003, Song et al. 2003). Similarly, with left main disease, is no longer a contraindication for OPCAB (Hirose, 2004). In case of left main disease, revascularization of the left anterior descending artery prior to the posterolateral branches is essential. IABP may be helpful to stabilize hemodynamics, while anastomoses, especially in a patient with poor ventricular function and left main disease.

### 4.4 Poor ventricular function

Although mutilvessel disease is no longer contraindication for OPCAB, incomplete revascularization has been observed more often in OPCAB than on-pump CABG. A large heart with poor ventricular function is difficult to manipulate and to expose the target vessel. Heart displacement without decompression of the heart is challenging in these patients with poor ventricular function and distended left ventricle.

### 4.5 Small and calcified target

The reasons for incomplete revascularization could be the quality of the target vessel, as an example a small, calcified, or intramyocardial coronary artery. Bypass to these small coronary arteries and/or calcified arteries is challenging, even under on-pump cardiac arrest. Tedious endarterectomy for calcified vessels should be performed under CPB. Extensive dissection of intramyocardial coronary artery under a beating heart carries risk of ventricular rupture and should be performed with a decompressed heart under CPB. Incomplete revascularization will negatively affect the patient long-term outcome (Scott et al., 2000, Synnergre et al., 2008). A hybrid procedure involving OPCAB and percutaneous intervention could be an option in these difficult OPCAB patients.

### 4.6 Emergent conversion to on-pump

In palatines with hemodynamic instability during anastomosis, emergent conversion to on-pump CABG is necessary. Conversion to on-pump surgery requires emergent arterial and venous cannulation, which may need to be done while CPR is in progress due to sudden ventricular arrhythmia or cardiac arrest. Emergent conversion from OPCAB to on-pump carries a ten-fold higher risk of operative mortality than elective OPCAB (Tabata et al.,

2006). One of the risk factors for emergent conversion is ischemic mitral regurgitation. Pre-existing ischemic mitral regurgitation may be accelerated during OPCAB due to displacement of the heart during anastomosis and due to distal ischemia.

### 4.7 Training

Cardiac motions during anastomosis are a major disturbance to the surgeon, and the OPCAB has a prominent learning curve. There is a direct correlation between the number of cases the surgeon has performed and the incidence of postoperative complications and graft patency. The surgeon with limited experience in OPCAB may produce a significant number of cardiac complications (Brown et al., 2001). Extensive training in performing OPCAB is necessary to improve patient outcomes.

### 4.8 Graft patency

Graft patency after OPCAB may be related to the surgeon's skill level. A previous study by Khan showed a decreased 3-months-graft patency rate in the OPCAB group compared to that in the on-pump group (Khan et al., 2004). However, the article was criticized because of the lack of the surgeon's adequate OPCAB experiences, lack of postoperative antiplatelet therapy with clopidogrel, and failure to use a suction device for stabilization of the heart (Dewey et al., 2004). A recent randomized trial by Puskas (Puskas et al., 2009), and the European study (Widimsky et al., 2004) independently confirmed similar 1-year graft patency rate between OPCAB and on-pump CABG.

## 5. Conclusion

Recent advances in surgical instruments and technique allows surgeons to perform OPCAB safely.

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| OPCAB for left main disease and multivessel revascularization is no longer a contraindication. |
| Except for patient undergoing redo CABG, hemodynamically compromised patients, and patient with poor target vessels, OPCAB can be performed by an experienced surgeon without increasing risks. |
| OPCAB requires a significant intensive training period. |
| OPCAB may expand the indications of CABG to patients with higher risks. |
| OPCAB contributes to shortening the length of stay and promotes an early recovery. |

Table 3. Summary of the advantages and disadvantages of OPCAB

Although there is a steep learning curve for OPCAB techniques, OPCAB provides a favorable or at least equivalent postoperative outcome compared to on-pump CABG, with minimal contraindications. OPCAB will significantly reduce the risk of CPB-related complications. These benefits of OPCAB are more significant in high-risk patients, and there is a possibility to expand the indication of CABG.

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