Coronary Artery Bypass Grafting in the Treatment of Heart Failure

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Heart failure remains a major medical burden with an estimated six million people affected in the United States of America alone making it the most common diagnosis in all hospital admissions [1, 2]. Coronary artery disease (CAD) with subsequent ischemic cardiomyopathy is the underlying cause of heart failure in roughly 70 % of all heart failure patients [3]. Indeed, myocardial infarctions (MI) are responsible for 750,000 deaths annually with an estimated 60,000 of the survivors developing congestive heart failure [4]. Transplantation has traditionally been the only surgical treatment for end stage heart failure but the scarcity of donor organs, the recipient suitability for organ transplantation as well as the rapid rise of heart failure have made this less than an ideal solution for all. Increasingly, surgical intervention has concentrated on coronary revascularization, valvular repair/replacement, ventricular restoration/remodeling, ventricular assist devices, stem cell therapy and external restraint devices [4, 5]. In this chapter, we aim to highlight the utility and selection of offering revascularization to the subgroup of heart failure patients who will benefit from this intervention.

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Role of Coronary Arterial Bypass Grafting (CABG) in Patients with Heart Failure

Patients with heart failure should be referred to tertiary care centers for the possibility of definitive surgical therapy. A comprehensive multidisciplinary team approach with discussions of the possibility of ventricular assist device and heart transplantation should be anticipated as both immediate and long-term treatment options in patients with ischemic heart failure. The initial goal in treating patients with heart failure is to determine whether or not there is any benefit to be gained from coronary arterial revascularization.

Assessment of Myocardial Viability

In order to assess whether these ischemic hearts benefit from surgical and/or hybrid revascularization, it is important to differentiate between hibernating myocardium and scarred

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non-functional muscle. In patients with ischemic hibernating myocardium, coronary revascularization will result in improved function. However, when the majority of the myocardium is necrotic and akinetic, coronary revascularization may be of no benefit with an unsurprisingly higher risk of mortality. Unfortunately, assessment of these patients is not straight forward as there is a mixed pattern of scar interspersed with viable tissue. This has led to some considerable debate over the utility of myocardial viability testing prior to any contemplated intervention without definitive answers from the much-anticipated STICH trial [6]. There are currently several available techniques to assess myocardial viability. Dobutamine stress echocardiography has mostly fallen out of favor given its higher false negative rates. The favored approach for viability testing includes nuclear imaging utilizing technetium-labeled radioisotopes or positron emission tomography (PET) tracers in both rest and stress conditions, single-photon-emission computed tomography (SPECT) myocardial perfusion imaging as well as cardiovascular magnetic resonance (CMR).

Nuclear imaging utilizing labeled tracers (PET) or photon-emission (SPECT) relies on the uptake of radiotracer by the cardiac myocyte and is by definition dependent on regional myocardial blood flow to show myocardial viability. Images can be obtained at both rest and stress to show perfusion defects correlating with myocardial ischemia, which are then classified as being either a reversible or fixed perfusion defect. CMR as an imaging modality has gained considerable traction within the last several years because of its ability to provide cine CMR showing segmental and global ventricular function in addition to perfusion imaging both at rest and at a delayed time to show myocardial viability and scar.

These advanced imaging techniques are useful screening tools to detect the presence of, as well as the extent of myocardial ischemia, further elucidating patients with ventricular dysfunction who have the greatest potential of benefit from revascularization. Indeed there is a consistent relationship between the amount of viable myocardium and the improvement of the left ventricular function following revascularization [7]. Some studies have suggested that the minimum viability of myocardium needs to be at least 50 % to show unequivocal evidence for myocardial improvement following reperfusion [8].

Benefits of Revascularization of Viable Myocardium

The risk of myocardial damage at the time of CABG, must be weighed against the benefit of revascularizing hibernating myocardium when deciding to operate on patients with heart failure – defined as on with an ejection fraction <35 %. Although mortality as high as 15 % has been reported, with appropriately selected and managed patients, mortality can be as low as 2–6 % [4]. In addition to a mortality benefit, revascularization has shown reverse cardiac remodeling with improved left ventricular function and quality of life [4]. It is thought that CABG mitigates the affects of maladaptive cardiac remodeling by preventing the distortion and enlargement of the left ventricular and hence keeping a smaller, more efficient LV geometry.

Technique of Surgical Revascularization

Perioperative Management

Coronary revascularization has emerged as a successful therapy for high-risk patients with heart failure. Medical optimization with beta-blockers, angiotensin converting enzyme inhibitors, angiotensin receptor blockers, diuretics, after load reducers and nitrates along with ionotropic support and optimal end organ function prior to coronary revascularization are key components on having a successful outcome. Liberal use of Perioperative intra aortic balloon pump (IABP), right ventricular support with phosphodiesterase inhibitors and inhaled prostaglandins has led to improved biventricular contractility and improved hemodynamics. Additionally, vasopressin to combat the chronic depleted stores of vasopressin levels and resultant perioperative vasodilatory state of these patients has been beneficial. Some subset of patients may need an early trial of hemodynamic improvement via initiation of intra aortic balloon pump support and if necessary the early ventricular assist device to support end organ perfusion while allowing the ischemic myocardium the required 2–3 days to regenerate depleted adenosine triphostate (ATP) stores. Although ischemic heart disease is the most common cause of heart failure, optimal treatment sometimes still is unclear.

Despite our improved knowledge of medical management, this remains limited in its effectiveness with a resultantly high mortality and morbidity. Revascularization should be the procedure of choice in this high risk group of patients with ischemic heart disease in the presence of impaired left ventricular function with special attention to factors affecting outcome such as: status of the patient, acuteness of presentation, right ventricular failure, and presence of good surgical targets. The keys to a successful operation requires a coordinated team approach with an experienced anesthesiologist and a cardiac surgeon comfortable with performing high-risk surgery with ventricular assist device backup.

In these high-risk patients, a Swan Ganz catheter and a transoesophogeal echocardiography (TEE) are important adjuncts in maintaining normal hemodynamic performance. A thorough TEE should be used to assess left ventricular wall motion, the presence and degree of valvular regurgitation, severity of atheroma of the aorta, and right ventricular function. Presence of more than moderate mitral regurgitation can aid in the decision to perform off pump versus on pump coronary revascularization. In view of the emerging data supporting mitral repair in the presence of ischemic cardiomyopathy repair of the mitral valve should be considered in patients with moderate or greater regurgitation.

Off Pump Coronary Arterial Bypass (OPCAB) Grafting

There have been many efforts to decrease the risk of surgical revascularization, especially in these high-risk patients. The challenge has been to offer complete revascularization to these patients while minimizing post procedure morbidity and mortality. Even though these high risk patients can be successfully revascularized with conventional cardio pulmonary by pass techniques, with CABG, there has been an interest in revascularizing these high risk patients off pump (OPCAB) in an effort to limit the myocardial injury associated with aortic cross clamping, ensuing global myocardial ischemia and cardioplegia related dysfunction. Off-pump surgery also aims to eliminate the ischemic inflammatory response elicited by cardiopulmonary bypass (CPB) [9].

Even though these high-risk heart failure patients can be successfully revascularized with conventional coronary artery bypass (CABG) techniques, there has been interest in performing this surgery off pump or without the aid of cardiopulmonary bypass. This is somewhat controversial; however, given to an improvement in techniques of myocardial protection and hemodynamic management.

In evaluating patients who would benefit from avoiding the "pump" or extracorporeal circulation, the primary indications are often:

1. Older age
2. Atherosclerotic burden in the ascending aorta and aortic arch
3. Renal dysfunction
4. Patients with significant myocardial dysfunction
5. Patients with poor pulmonary function
6. Patients with severe liver dysfunction
7. Patients with underlying disorders that may preclude anticoagulation required for CPB

Preoperative planning is also very important in successful off pump surgery. It is necessary for the surgical team to know the patient's anatomy, the vessels to be bypassed and other diseased coronary vessels that may be involved. There should be a clear plan for the choice and type of conduit, the vessels to be revascularized as well as alternatives.

It seems clear that revascularization is indicated in the management of heart failure and ischemic coronary disease [10]. Particularly in this high group risk of patients, OPCAB seems the preferable approach. A recently published study from The Society of Thoracic Surgeons National Database showed decreased risk of death, stroke, major adverse cardiac events, prolonged intubation and transfusion rates [11]. We cannot; however, underscore the importance of complete revascularization in these patients with heart failure. Complete revascularization is vital in achieving good results in patients with severe left ventricular dysfunction [12]. Completeness of revascularization has been shown to improve early survival in young and elderly patients and is a critical factor in patients with left ventricular dysfunction. The liberal use of balloon pump support, appropriate ionotropic support, hemodynamic monitoring, and perioperative analgesia are all important in the multi-disciplinary approach to these patients. The importance of preoperative optimization allows for a successful coronary revascularization in patients with heart failure and has been shown to improve survival in this cohort of patients with low ejection fraction [13]. It has also been shown in a large database that CABG reduced the likelihood of additional readmissions in the ensuing year over either medical management or percutaneous intervention [14]. A comparison of a small sub-group of patients with ejection fraction <35 % showed that OPCAB patients had similar results in providing this benefit to patients undergoing conventional CABG. OPCAB mortality in patients with unfavorable characteristics such as dysfunctional left ventricle and left main coronary disease can be safely performed with a mortality rate near 2.5 % [15]. Another large series looked at a high-risk group of patients (low ejection fraction, advanced age, left main disease, and an acute myocardial function and re-do coronary artery surgery) undergoing OPCAB and compared them to a similar cohort of patients undergoing conventional CABG on CPB. The results showed that that average number of grafts were comparable (3.0 in the OPCAB group and 3.2 for the on-pump group, the hospital mortality was 3.2 % for OPCAB and 4.5 % for the conventional CABG group respectively) [16]. Additionally, patients undergoing OPCAB surgery with a depressed ejection fraction (<40 %) showed significant improvement in their post-operative ejection fraction. Another study looking at a group of high risk patients (defined as a EuroSCORE ≥6) undergoing isolated coronary revascularization with and without cardiopulmonary bypass was compared with propensity score matching. This showed that in a propensity matched group of 510 OPCAB with 510 conventional CABG, that the OPCAB group had better early outcomes with similar clinical results [17]. The 30-day mortality was higher in the conventional CABG group, 5.9 versus 3.1 %. There was also a significantly lower evidence of cerebrovascular accidents (CVAs). A multivariate logistic regression analysis, confirmed that the use of cardiopulmonary bypass was an independent predictor for a higher early mortality, (odds ratio of 2.0) as were CVAs and early major recurrence of chest pain. Five-year freedom from major events (myocardial infarction in a grafted area, need for myocardial coronary re-intervention and any cause mortality) were similar in both groups.

Heart failure patients tend to have more than just one co-morbidities and are thus a set up for post-operative morbidity and mortality. Patients with this degree of systemic disease along with advanced left ventricular dysfunction do not tolerate super imposed bypass with resultant post-inflammatory injuries to their organs [18]. An early report comparing the techniques of OPCAB to conventional CABG in patients with ejection fraction <35 % showed that there was a higher prevalence of lower ejection fraction (defined as <20 %) in the OPCAB group. Additionally, the average number of grafts was similar with a similar percentage of internal thoracic or mammary arteries being used (see Figs. 5.1 and 5.2). There seemed to be a trend towards lower operative risk in the OPCAB group with better long term survival in these patients done off pump versus the on pump patients [19].

Special Considerations in Choice and Technique of OPCAB

There are certain instances when OPCAB should not be the preferred method for revascularization

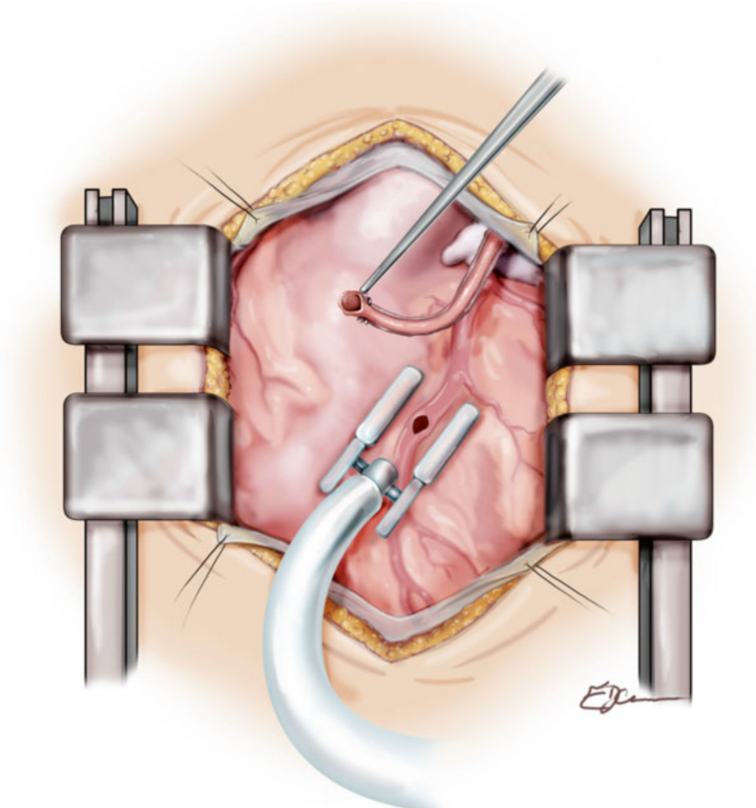

Fig. 5.1 Schematic showing a left internal mammary artery (LIMA) being readied for anastomoses to the left anterior descending (LAD) artery. The myocardium is being stabilized by a suction based stabilizing device to facilitate the LIMA to LAD anastomosis

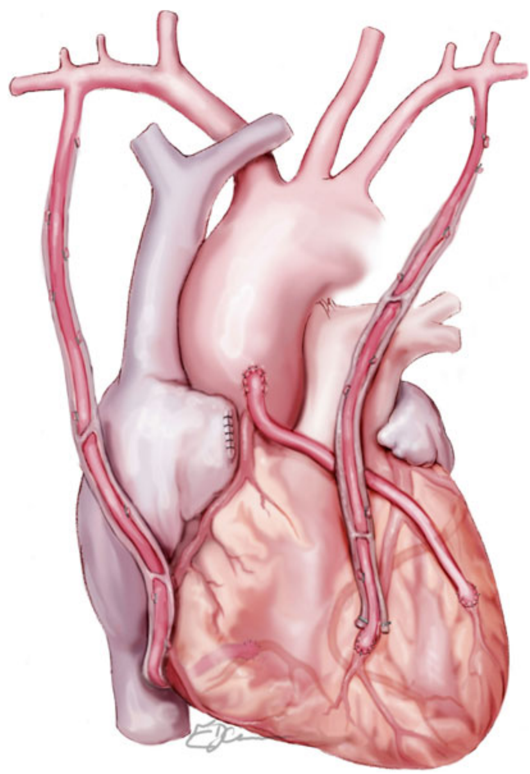

Fig. 5.2 Schematic showing the use of the left internal mammary artery as a bypass conduit to the left anterior descending artery as well as the right internal mammary artery to the posterior descending coronary artery. Additionally, an aortocoronary graft to a diagonal coronary artery is shown

[20]. Particular attention should be paid to the presence of and degree of mitral regurgitation. In the presence of greater than moderate mitral regurgitation, patients should have the mitral valve repaired or replaced [21]. A retrospective study compared 45 OPCAB versus 102 conventional CABG recipients with ejection fractions <30 % and although there were comparable incidence of adverse events, there were fewer grafts performed in the OPCAB group [22]. Similarly, another large study of 355 patients undergoing revascularization with an ejection fraction of ≤30 % showed that the number of grafts in the OPCAB group was 2.8, compared with 3.3 for the on pump group [15]. Once again, the importance of the completeness of revascularization cannot be understated.

A major deterrent to OPCAB surgery is the tolerance of patients to undergo the degree of cardiac manipulation and displacement that is necessary to perform total revascularization. Continual communication between the surgeon, anesthesiologist, nursing staff and perfusionist are vital to ensure smooth conduct and success of the operation. By nature, there will be alterations and swings in hemodynamics as the position of the heart is manipulated; however, careful alterations in position combined with cooperation and active participation of the anesthesiologist can minimize any systemic effect. There are some surgical tenants to adhere to in the performance of OCPAB surgery:

1. Ensure effective and clear communication with the team of anesthesiologists, nurses and perfusionists as to the planned procedure, vessels to be grafted, alternate conduits and potential exit or bail-out strategies before the procedure.
2. Try to minimize large manipulation of the heart by lifting the heart. Rather, use deep pericardial stay sutures allowing immediate assessment to whether or not the patient will tolerate off-pump surgery. If not, convert to early on-pump surgery as a strategy.
3. Decide on the availability and suitability of conduits to be harvested and ensure the LIMA is the first graft for the LAD graft. Thereafter, proceed with a sequence to effect revascularization to the next most ischemic area. If another pedicle graft is used, such as the RIMA, perform this next. If aorto-coronary grafts are planned, try to perform the aortic anastomosis first so that when the distal anastomoses are completed, there is instant revascularization of that territory.
4. If there are issues with rhythm, use atrial pacing or dual chamber pacing with ventricular pacing wires placed on both ventricles for hemodynamic stability (see Fig. 5.3).

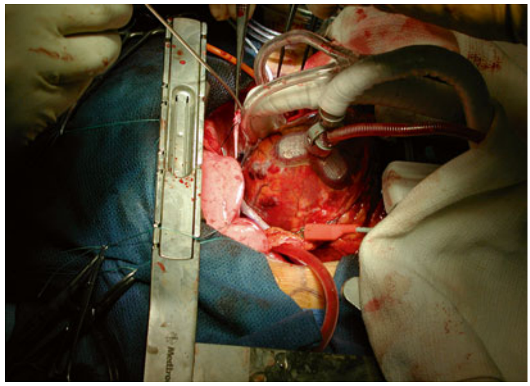

Fig. 5.3 Operative photograph showing facilitation of coronary grafting with heart stabilization with a suction device along with pacing. Note the pacing cable at the bottom of the picture

In patients with severe heart failure particularly with left main coronary disease, a useful technique of positioning the heart is by gently putting a glove filled with warm saline behind the heart positioning the LAD into the center of the surgical field and allowing easier access for grafting. The advantages of grafting the LAD first is establishing coronary flow through the septal perforators into the septum and providing better tolerance of the myocardium to further manipulation. There are certain instances when off-pump surgery may not be possible. These are encountered in patients with very stiff myopathic hearts that do not tolerate manipulation. In these cases, there are two options possible; either leaving the lateral wall revascularization to percutaneous intervention or using pump assisted, beating heart CABG (so called "pump assisted") method. Discounting the inflammatory cascade from use

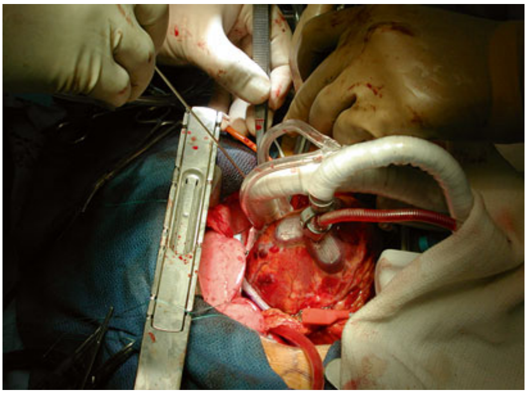

Fig. 5.4 Operative photograph showing an apical positioning device and a stabilizer (both suction based) used to expose the circumflex artery along the lateral wall of the left ventricle

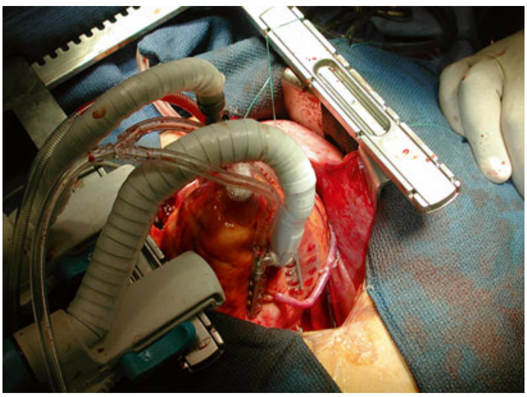

Fig. 5.5 Operative photograph showing a completed distal anastomosis to an artery on the inferolateral wall of the left ventricle

of cardiopulmonary bypass, this may be the safest approach in sick patients with very low ejection fractions and profound left ventricular dysfunction. Another helpful alternative may be to use intra-aortic balloon counter pulsation to provide circulatory support for tolerance of OPCAB manipulation. In some studies of patients with an EF ≤25 %, one predictive factor of better outcome was pre-operative balloon pump insertion as compared to those who did not receive counter pulsation support. That being said, there is no doubt that the use of positioning and stabilizing devices has made a huge difference in the ability of surgeons to operate on vessels on the lateral and inferior wall (see Figs. 5.4 and 5.5). These suction, traction or pressure-based devices allow for stabilization of regions of the heart to allow for an operation. The most successful of these is the Medtronic Octopus, which is a suction based device initially developed at the University of Utrecht, Netherlands. Most off-pump procedures require a combination of a positioner and a stabilizer for each of the distal coronary anastomoses.

In general the OPCAB sequence of the operation follows a philosophy as outlined in the above tips. The goal should be for complete revascularization. In some instances positioning of the heart can be performed by opening of the pleura and allowing the right heart to be displaced into the right chest. This allows easy access to the circumflex vessels with minimal hemodynamic disturbance. However, this can be of concern if the LIMA has been grafted to the LAD as there may be too much tension to allow distraction of the heart and as such this needs to be considered in the pre-operative graft sequence planning. The proximal anastamoses can be performed to the aorta with a single partial clamp or by avoiding the clamp with the Heart String (which is a clampless way of providing a safe aortotomy) as depicted in Fig. 5.6.

In summary, OPCAB revascularization has been shown to be as effective and as safe as conventional coronary arterial bypass in experienced hands [23]. In fact, in patients with multiple risk factors, particularly those with heart failure with a low EF, OPCAB with complete revascularization can be more beneficial. To provide for reproducible and successful outcomes; however, the procedure needs to be performed by an experienced team. There needs to be a vigilant and responsive anesthesia team along with seamless communication between all team members. It is essential for the surgeons to inform the anesthesiologists about the number of grafts required, the sequence of grafting, the nature of the occlusion of the target vessel among other details of the proposed procedure.

Another useful technique, which is less invasive and mostly performed off-pump is the MICS (Minimally Invasive Cardiac Surgery) CABG. This involves a left minithoracotomy,

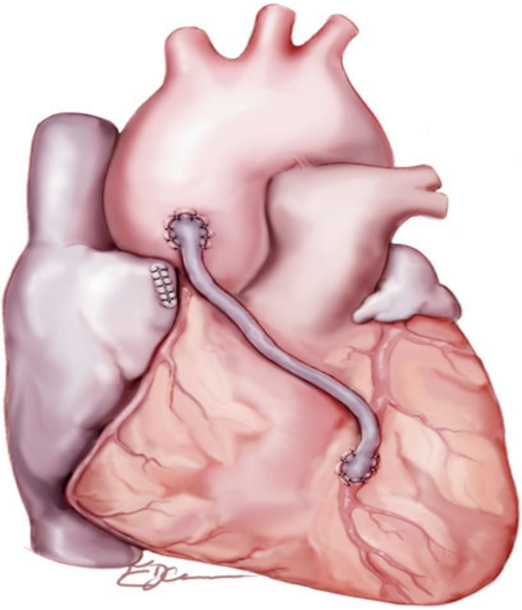

Fig. 5.6 An illustration depicting a single saphenous vein graft to the left anterior descending artery using the proximal anastomotic technique of interrupted U-clips. This can be a particularly useful strategy in re-operative surgery where the proximal anastomosis can be performed without a clamp

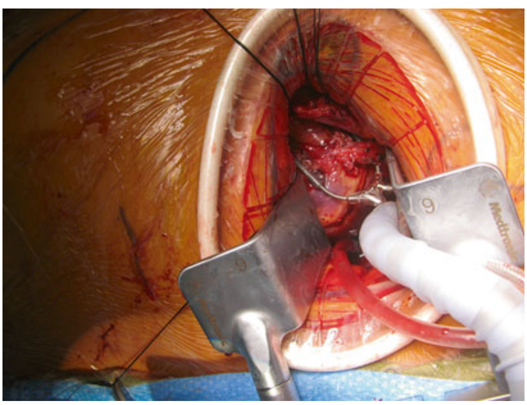

Fig. 5.7 Shows a LIMA to LAD anastomosis complete through this approach

with harvest of the left internal mammary artery through the lateral incision. The completion of the distal anastomoses, especially LIMA to LAD can be performed safely through this incision.

Figure 5.7 shows a LIMA to LAD anastomosis complete through this approach.

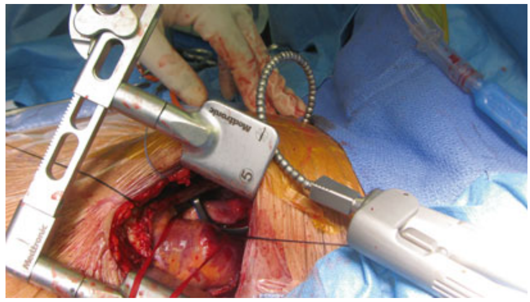

Fig. 5.8 Shows a trans-thoracic partially occluding Cygnet clamp used on the ascending aorta, in preparation for a proximal anastomosis of a vein graft

An experience of over 100 patients with this technique in high risk patients over the past 3 years (personal experience of JR), showed satisfactory results with an acceptably low mortality of 2 % and low risk of peri-operative complications. This technique is technically more demanding and needs special equipment such as a specific retractor to facilitate LIMA harvest, custom made partial occluding clamps for the ascending aorta, long single shafted instruments to allow handling of the grafts, etc.

Figure 5.8 shows a trans-thoracic partially occluding Cygnet clamp used on the ascending aorta, in preparation for a proximal anastomosis of a vein graft.

Anesthesiologists have to continuously be conscious of the hemodynamic monitoring, filling pressures and ventricular wall motion assessment with trans-esophageal echocardiography to facilitate an expeditious and safe operation. One lung anesthesia has to be available to facilitate the left mini-thoracotomy MICS CABG approach.

Hybrid Revascularization

In a subset of patients with severe heart failure who may not be able to recover from a sternotomy or partial sternotomy, a hybrid approach is a very attractive option. Usually the LIMA is grafted to the LAD in a minimally invasive fashion. This can be performed by a thoracotomy or sub-xyphoid minimally invasive directed coronary artery bypass (MIDCAB) approach [24].

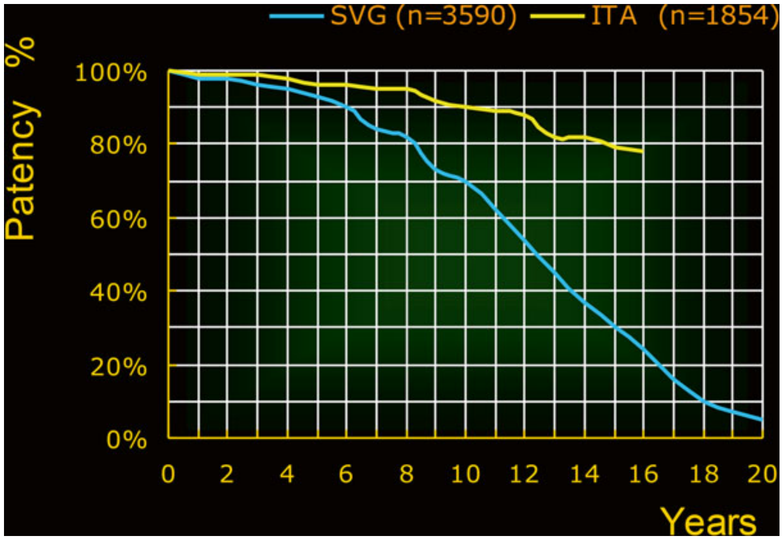

Fig. 5.9 Cumulative patency of saphenous vein grafts compared to the internal thoracic (mammary) artery (Kind courtesy of Prof Brian Buxton, University of Melbourne and Epworth Hospital Databases – maintained by Prof Buxton and Dr J Fuller)

The other less important vessels can be staged with percutaneous stenting thereafter. In general, the sequence is to perform the LIMA-LAD bypassing followed by a percutaneous intervention – either in the same setting or within 48 h. This two-stage sequence of revascularization has the major benefits of providing the mortality benefits of an LAD protected by a surgical LIMA graft as well as the ability to evaluate this anastomosis and potentially intervene with angiography. In view of the improving stent technology, this may become the future of revascularization. Hybrid revascularization entails surgical revascularization combined with trans-catheter therapy. This hybrid approach allows for a less invasive approach to provide complete revascularization. It can also be used in the reoperative setting where the back wall vessels can be grafted through a thoracotomy with inflow from the descending aorta with stenting of the other vessels.

Choice of Bypass Conduits

The perceived notion that all-arterial grafts should be used for all bypass grafting stems from the long-term patency data comparing the internal mammary (or thoracic) artery patency rates with that of saphenous vein grafts (SVG). A large database utilizing data over two decades shows a widening gap between the patency rate of SVG as compared to ITA (internal thoracic (or mammary) grafts). The patency of the ITA remains excellent throughout the follow-up period (Fig. 5.9).

This data, along with others, has made the use of the left internal mammary artery graft to the LAD the standard of care [25, 26]. This finding spawned the idea that two arteries are better than one and three better than two (see Figs. 5.10 and 5.11). Some have argued that this may lead to a lower prevalence of heart failure in patients who have previously received multiple arterial bypass grafts [27].

Despite these arguments, the standard coronary artery bypass procedure in the United States utilizes a single left IMA and saphenous vein conduits from the thigh. Surprisingly, coronary artery surgery in emerging markets such as India and China show a great deal more sophistication, with over 60 % of patients in India receiving at least two arterial grafts. In addition to the use of bilateral internal mammary artery use as conduits of choice, a great deal of interest has emerged in the use of a patient's radial artery from the non-dominant arm. Despite success at some institutions, other centers have not been as apt at employing this as a bypass conduit. In the early mid-term results of the RAPCO (Radial Artery Patency and Cumulative Outcomes) study, there

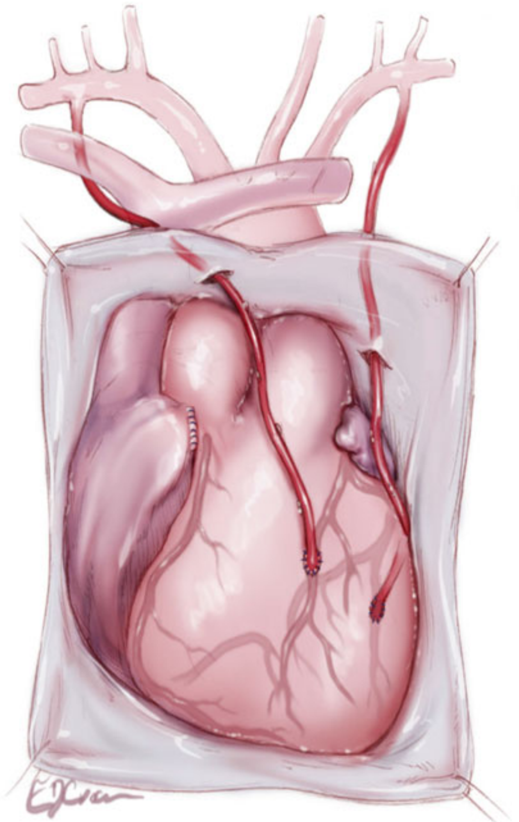

Fig. 5.10 Illustration depicting bilateral pedicled skeletonized internal mammary arterial (IMA) grafts. The left IMA to an obtuse marginal of the circumflex and the right IMA to the left anterior descending coronary artery

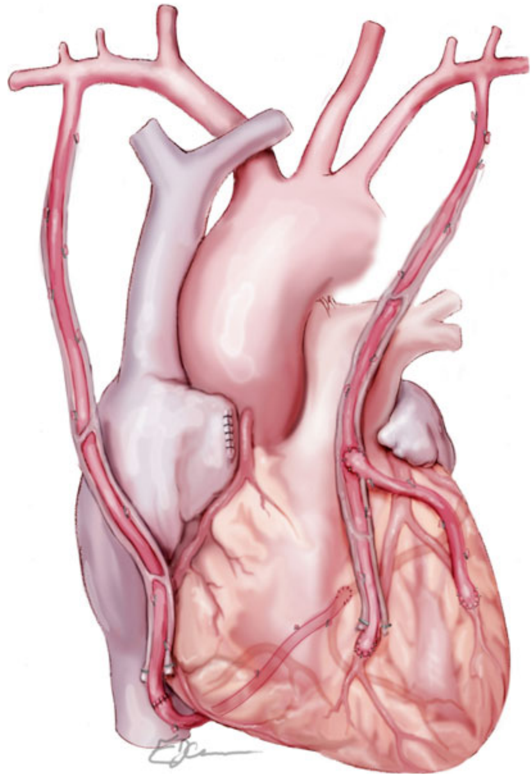

Fig. 5.11 All arterial grafting with no aortic manipulation. Two pedicled IMA grafts with one radial artery segment extending the RIMA and the other radial artery segment hooked up to LIMA as inflow. Figure 5.5 shows all arterial grafts performed without any aortic manipulation, which truly provides the full benefits of off-pump surgery. Note that one limb of radial artery has been used to prolong the RIMA, providing a composite graft that can revascularize the inferior wall. The other segment of radial artery is anastomosed to the mid-portion of the LIMA, end-to-side to allow grafting of the lateral wall

seems to be a hint at equivalent survival and graft patency between the radial artery and the right internal mammary artery – however, the primary end points and final results will not be available until 2014 [28].

Discussion

Off-pump CABG with complete revascularization has been shown to be as effective and safe as conventional coronary artery bypass grafting. In patients with heart failure and severe ventricular dysfunction with an ejection fraction of ≤35 %), complete revascularization can also be performed using OPCAB. This technique can minimize the inflammatory cascade that results from the cardiopulmonary bypass circuit and has the potential of being more beneficial in this high-risk population. In order to have a successful and complete revascularization; however, these patients need to be medically optimized prior to the intervention and have the procedure performed by an experienced team to be successful. The experienced heart failure surgeon needs to have the entire armamentarium to coronary revascularization and be readily apt at dealing with the various clinical scenarios that can arise.

Key Points

- Complete revascularization via coronary arterial bypass grafting surgery provides the definitive primary modality in the treatment of ischemic heart failure as a consequence of coronary artery disease.
- Off-pump coronary artery bypass surgery may have particular advantages in this high-risk patient population.
- Appropriate choice and use of arterial conduits may confer protection against future episodes of heart failure.
- Coronary artery surgery remains the cornerstone for the prevention and treatment of ischemic heart failure.

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