Multivessel Coronary Bypass Grafting With Minimal Access Using Cardiopulmonary Bypass (Port Access Approach)

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Port access coronary artery bypass grafting (PA-CABG) has evolved significantly since its introduction in 1996. New technological developments, procedural changes, and operator experience have led to improved understanding of the potential benefits and pitfalls of the procedure. At our hospitals, Memorial Mission Hospital and New York University Hospital, more than 600 coronary revascularizations have been performed with the port access platform. This article reviews the technique, patient selection process, and results associated with the procedure.

PRINCIPLES

The technique of PACABG is based on the principles that have made standard on-pump CABG a successful operation for treating coronary artery disease. Cardioplegic-induced cardiac arrest with cardiopulmonary support allows for improved visibility, enhanced precision of anastomosis, and cardiac decompression with access to all regions of the heart for complete target revascularization. With port access, the cardiac operation is performed via a small anterior thoracotomy while the patient is maintained on a new system of cardiopulmonary bypass that uses peripheral cannulation to support the patient during peripherally manipulated cardiac arrest. Thus, the patient's recovery is not impaired by skeletal healing. The hypothesis is that the sternotomy itself slows the recovery process and adds morbidity to the operation that may be avoided with peripheral perfusion. This cannula system was refined through extensive laboratory studies confirming its efficacy and safety. Reliable myocardial protection and cardiopulmonary support have been documented with this technique.[1]

When clinical trials were begun in 1996, it became evident that significant changes in the operating room were required to achieve excellent outcomes. First, the anesthesia, perfusion, nursing, and surgical staffs were required to learn new skill sets. Second, communication within and between these disciplines, along with critical analysis of each member's role, required review and expansion. This team approach has been shown to be one of the crucial requirements to successful adoption of this new procedure. The importance of nonsurgeon input to the procedure cannot be overemphasized. Successful application of PACABG is not solely about a surgeon mastering a new operation, but rather about an operating team bringing together a critical mass of skills to perform this new procedure.[2]

The initial CABG experience was focused on the area from the left internal mammary artery (LIMA) to left anterior descending artery (LAD) bypass.[3] Subsequently, with operator experience, multivessel procedures became more common. With these initial multivessel procedures, graft inflow was based on the LIMA. The LIMA was anastomosed to the LAD, and radial arteries or saphenous veins were taken as side grafts to non-LAD targets. As surgeons continued to modify the operation, access to the aorta became routinely achievable. This enabled the more conventional operation of non-IMA conduits to be based off the aorta, This significantly decreased operative times and simplified and improved the applicability of the procedure.[4]

PATIENT SELECTION

Patient selection has been refined significantly with increased experience. Body habitus is a critical concern. Obtaining good exposure may be difficult in obese patients or women with large breasts. This approach likewise may be difficult in patients with pectus defects. This approach may be easier in patients with significant obstructive pulmonary disease, in whom the intercostal spaces are enhanced; however, the patient must be able to tolerate single lung ventilation if the LIMA is to be harvested. Any patient with a history of significant chest wall trauma should be closely evaluated. Generally, in women the chest wall is less rigid and IMA mobilization is easier.

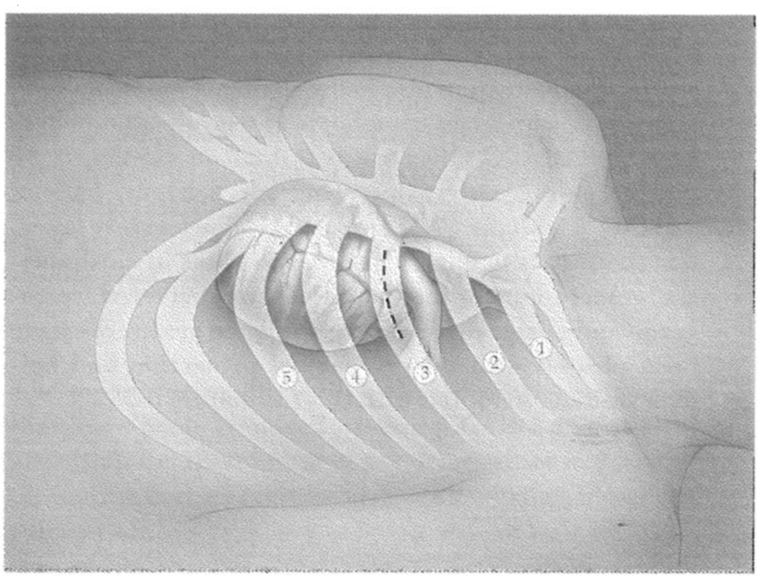
The quality of the distal targets should also play a role in the selection process. An open procedure should be considered in patients with severe distal disease, who may require endarterectomy. Adequate space to perform the endarterectomy may not be afforded through the small anterior thoracotomy. Small distal targets in a multigraft procedure may be best performed as an open procedure. Finally, the number of distals to be performed must be considered. Constructing 5 or 6 distal anastomoses while ensuring proper graft orientation and length through the small incision can be challenging and may best be done in an open procedure.

One of the principal differences between PACABG and conventional CABG is the former's reliance on transesophageal echocardiography (TEE) during the procedure. TEE is used to screen patients for particular anatomic contraindications, assist with cannula placement, monitor intraoperative results, and streamline the operation. Therefore, the anesthesia staff must be facile in its performance, and surgeons, along with their anesthesia colleagues, must be accustomed to its interpretation.

After TEE induction, the descending aorta is carefully examined for atheroma susceptible to retrograde embolization with femoral perfusion. Next, the ascending aorta is evaluated for mobile or protruding atheroma at risk for disruption with aortic manipulation. Either of these findings may call for changing the operative approach. If atheromas are isolated to the descending aorta or if severe peripheral vascular disease has been noted preoperatively, then conventional CABG, port access with direct aortic cannulation, or an off-pump strategy may be appropriate. Similarly, discovery of an ascending atheroma will drastically change the planned procedure. Potential operative options all stress a "no touch" strategy regarding the diseased aorta. Aneurysmal disease of the abdominal or thoracic aorta are contraindications for using the femoral platform. Direct aortic cannulation is an option in these patients. Prior aortic dissection is an absolute contraindication for port access surgery. The finding of significant aortic insufficiency or an enlarged ascending aorta that prohibits antegrade cardioplegia delivery or balloon occlusion also may preclude port access surgery. Each of the aforementioned variables must be assessed with TEE to ensure a seamless operation.

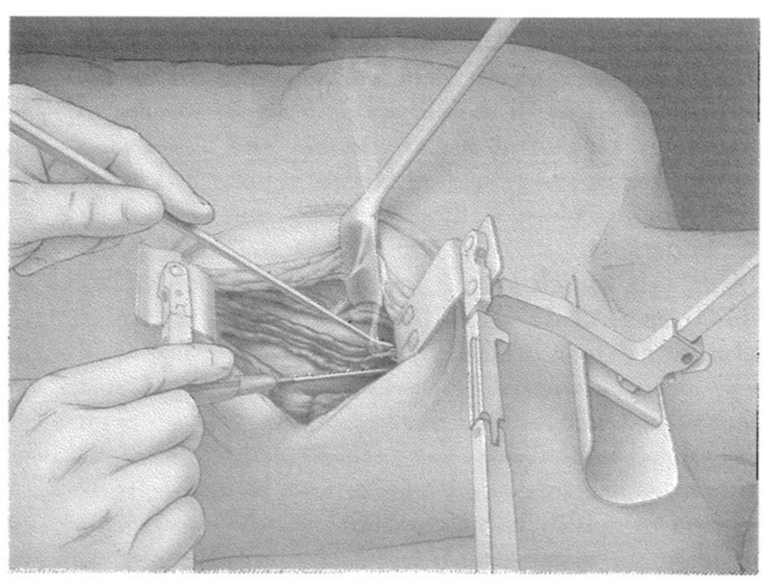
Once the TEE examination is completed, the anesthesiologist may place the right heart vent and coronary sinus catheter. TEE is used to locate the coronary sinus and guide placement of the retrograde cardioplegia catheter. We use retrograde cardioplegia in more than 90% of PACABG procedures. Besides the numerous benefits of retrograde cardioplegia in general, retrograde administration also helps eliminate aortic balloon migration, which can complicate antegrade administration in PACABG. Because transballoon pressures do not increase greatly with retrograde delivery, balloon stability is enhanced. On relatively short arrest cases, our strategy is to administer the first liter of cardioplegia antegrade; additional doses are delivered retrograde and antegrade through completed grafts. We have been pleased with the myocardial protection and balloon stability achieved with this technique.

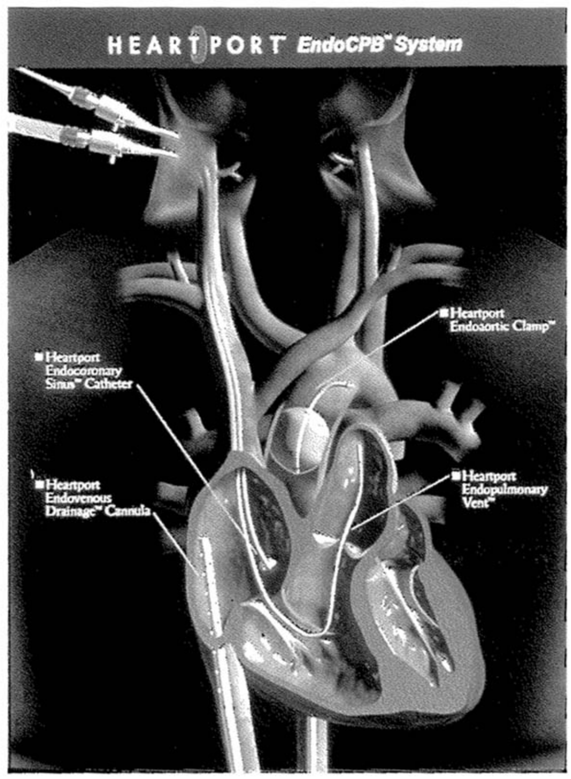
SURGICAL TECHNIQUE



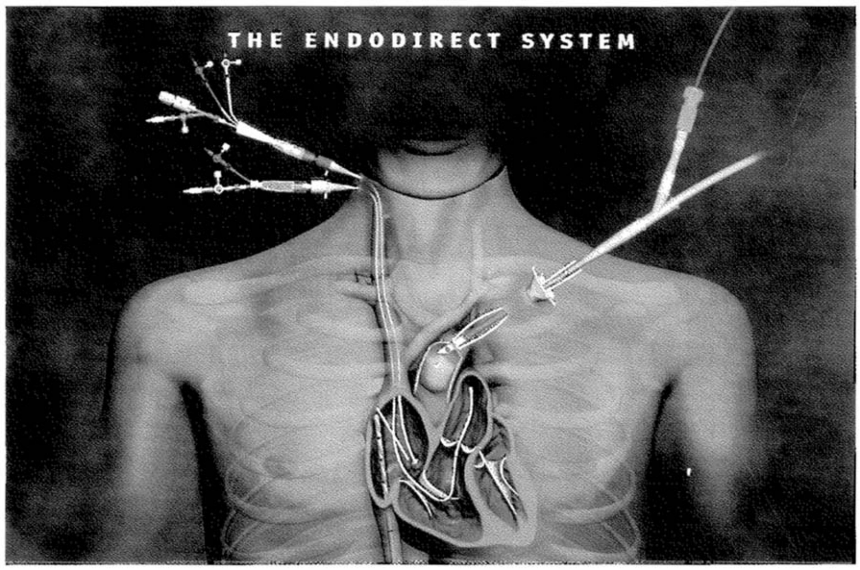
1 The surgical procedure begins with a wide prep that allows for conversion to standard CABG if required. (Conversion is necessary in less than 5% of cases.) External defibrillatory pads are applied in the event of dysrhythmias before or after cardiopulmonary bypass. The skin incision is made over the third intercostal space, starting medially at the sternal edge and extending laterally 5 to 7 cm. This is in contrast to a previously favored lower incision. The third interspace allows for an improved aortic exposure, which may be required for direct aortic cannulation for arterial return and for easier access for proximal graft anastomosis. This higher approach provides for more conventional techniques by enabling antegrade arterial perfusion and aortic graft inflow for non-LAD targets.

2 The LIMA is localized in the medial portion of the incision. It is carefully mobilized cephalad under direct vision. Various retractors can enable safe dissection. The dissection is done slowly to preserve the integrity of the artery and to prevent any bleeding, which can be problematic in the small incision. Distal mobilization can be difficult secondary to visualization. A 30° thoracoscope introduced through the lateral portion of the incision greatly enhances visualization and dissection. The LIMA generally can be mobilized from the level of the brachiocephalic vein to the sixth rib with this technique.



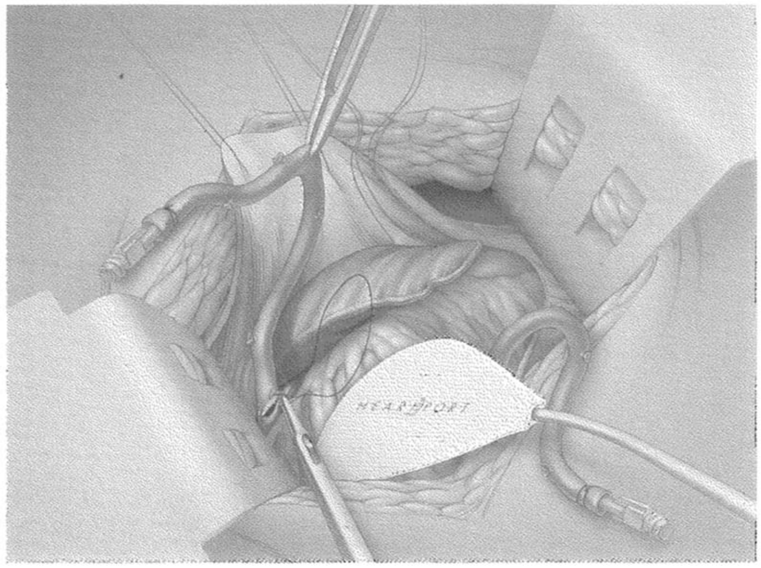


3 After the LIMA is harvested, the patient is heparinized and prepared for cannulation. There are two options for cannulation. The original system of endocardiopulmonary bypass uses femoral venous and arterial cannulation. The long venous line is advanced initially over a guidewire under TEE surveillance into the right atrium. The venous line is introduced through a pursestring suture placed in the bulb of the saphenofemoral junction. The femoral vein itself is never snared or manipulated, reducing the risk of venous thrombosis. Additionally, venous return from the leg may continue around the cannulae during the procedure. Subsequently, femoral artery cannulation is performed with the "Y" arterial cannula. This cannula is designed for simultaneous perfusion and placement of the aortic balloon occluding catheter. This balloon-tipped catheter is advanced over a guidewire, and its intraluminal position is confirmed with TEE. Strict adherance to modified Seldinger technique is observed with all line placements. Our preference is for femoral cannulation. However, in cases of significant peripheral vascular disease, or in situations where antegrade flow is desired, direct aortic cannulation can be used for arterial return and aortic balloon occlusion.



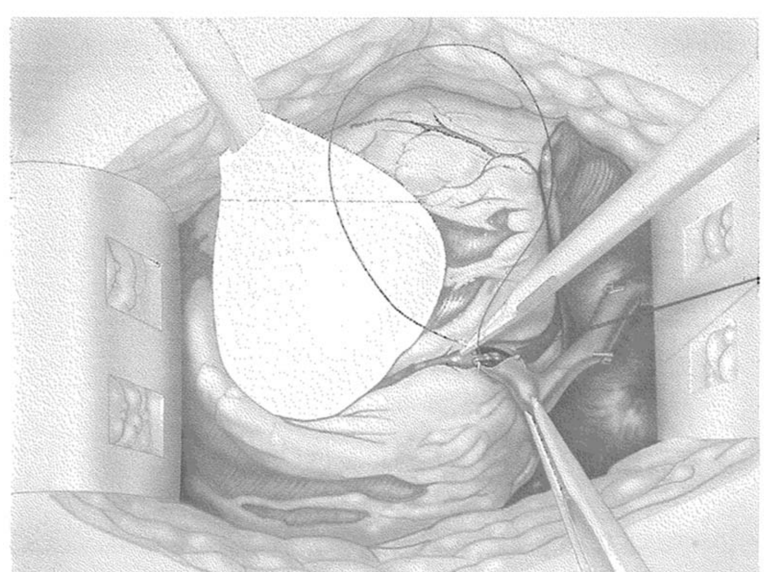
4 Direct aortic cannulation allows placement of the aortic return and balloon occluder into the distal ascending aorta. Potential advantages of this include antegrade flow and decreased tendency for balloon migration, which can be problematic in an operator's early experience with the femoral system. The cannulation sequence differs somewhat from that for the femoral system. Exposure of the distal ascending aorta is gained after mobilization of the IMA. A pericardiotomy is made and extended toward the brachiocephalic vein. Traction sutures are placed along the right pericardial edge. Sutures are then placed along the right margin of the pericardium into the region between the aorta and the superior vena cava. Traction on these sutures will marsupialize the aorta into the field and enhance exposure for cannulation. The cannula is then introduced via a separate thoracostomy along a favorable lie into the aorta, generally through the first interspace. The cannula has a special incising blade that enables its insertion. Again, TEE is used to ensure proper placement of the aortic balloon occluder.

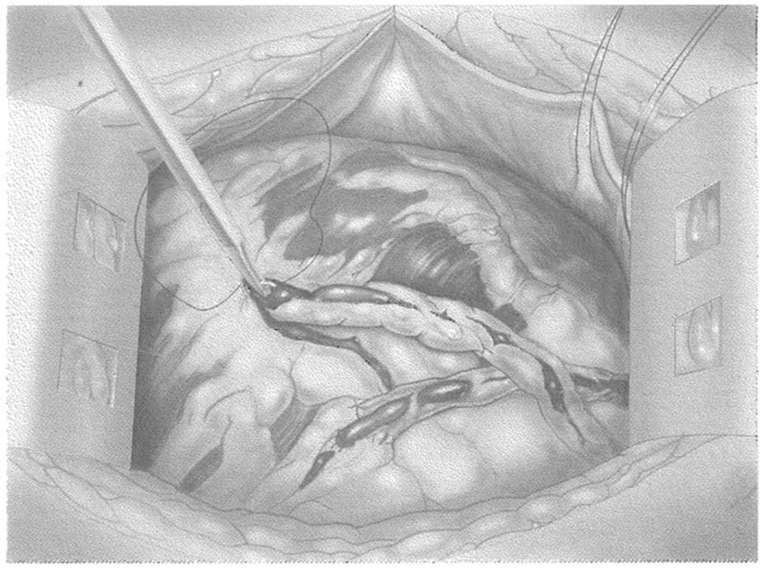
Initiation of bypass is a slow process that must be carefully monitored. TEE is used to visualize the descending aorta with initiation of retrograde flow to ensure that no flap is raised. Any manipulation of the balloon catheter or inflation of the balloon is observed with TEE. Once full cardiopulmonary bypass has been established, the extrapericardial fat is mobilized as a pedicle that can be placed over the pericardial opening after grafting. This will help prevent the IMA from adhering anteriorly to the incision or the lingula from angulating the IMA medially. The pericardium is then opened, and the aorta and the targets are visualized. Cardiac arrest may then be obtained by inflating the endoclamp and delivering cardioplegia. The endoclamp is inflated while being visualized with TEE. Once the endoclamp is filled, it is snugged toward the aortic cannula under direct aortic cannulation. In the event of femoral cannulation, direct pressure just distal to the balloon with a small sucker tip ensures balloon stability with antegrade cardioplegia delivery.



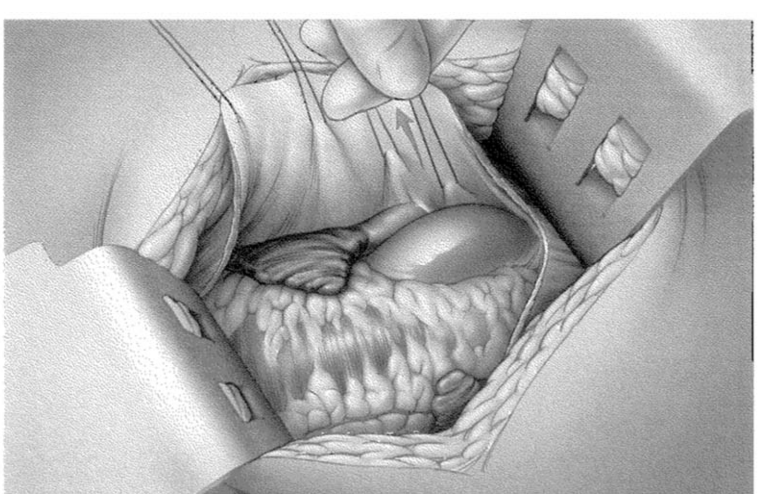
5 The arrested, flaccid heart is easily mobilized within the pericardium for the performance of distal anastomoses. The proximal right coronary artery is readily visualized before the crux. However, the extension of the right coronary artery beyond the posterior descending branch can be difficult to expose. The posterior descending branch of the right coronary artery is easy to expose. It travels directly toward the surgeon as he or she stands at the patient's left side. The second assistant is best positioned at the head of the table for exposure. An angled Debakey clamp with a folded sponge in the jaws works well for retraction and is out of the surgeon's way. By folding the acute margin of the heart cephalad with the angled Debakey clamp, the distal right coronary artery and posterior descending branch come into the operative field. In some cases, placing gauze sponges along the diaphragmatic surface of the pericardium can assist in lifting the target into the field. Our preferred target in the right circuit is the posterior descending artery. Sequential grafting of the right with port access can be problematic. We prefer long single-shafted needle holders, which are especially helpful in sewing the right coronary and obtuse marginals. In patients with single-vessel right coronary artery disease, left anterior thoracotomy is the incision of choice unless there is only a very proximal right coronary obstruction. Because the distal route of the right coronary artery moves away from the right anterior thoracotomy, obtaining adequate control of the artery through this incision can be very difficult.

6 The circumflex marginal branches are exposed using the same instrumentation. The heart is rolled in a clockwise fashion with the apex elevated toward the right shoulder. Traction sutures along the left edge of the incised pericardium are lifted and secured to assist in rolling the heart. Again, sponges may help maintain the exposure; placing the sponges beneath the coronary sinus will help stabilize the position. Visualization of the obtuse marginals is generally excellent, frequently better than with sternotomy. Sequential grafts are easily accomplished, as the exposure readily lends itself to visualization of all lateral wall targets without adjusting the field.

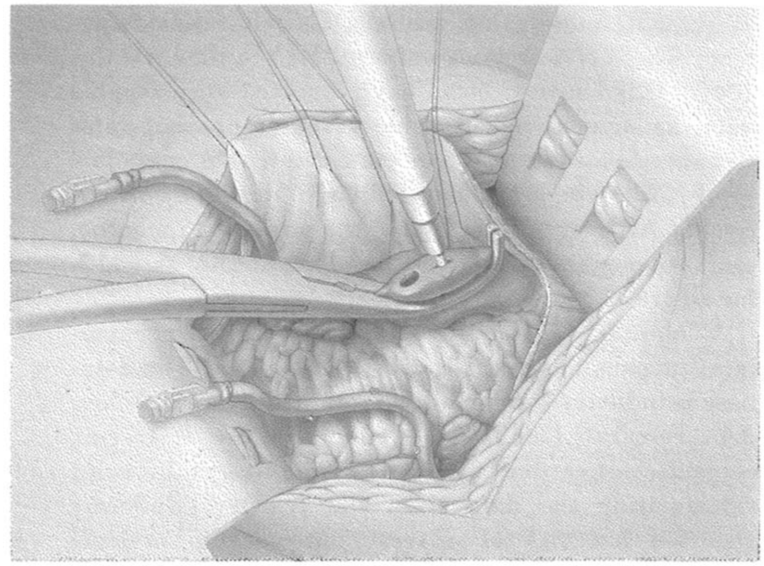




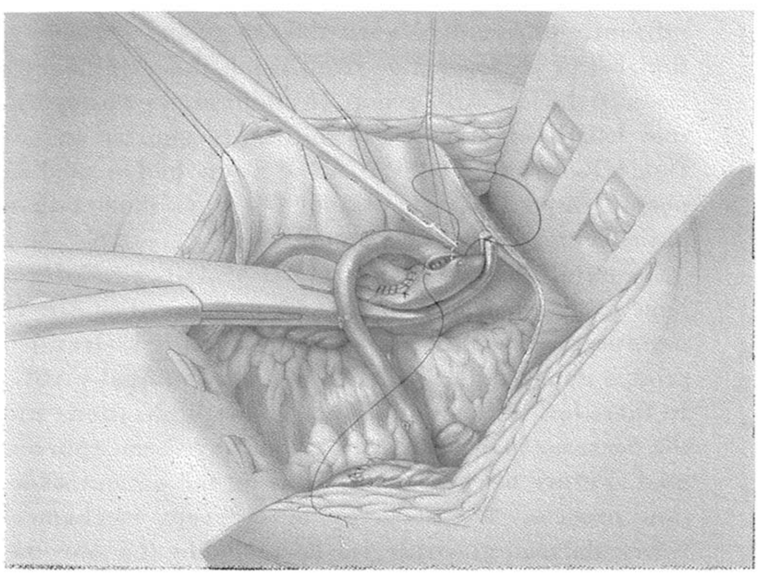
7 The anterior descending and its branches are the easiest to expose. The heart usually requires no specific manipulation to expose the arteries, as they are directly beneath the incision. At times, the third interspace incision may decrease exposure of the distal ⅔ of the LAD. In this situation, sponges placed at the apex of the heart will bring this portion of the artery into the field and facilitate the anastomosis. The anastomosis between the LAD and IMA should be protected, as it will frequently come to rest beneath the incision and can possibly become involved in adhesions. Another concern is the lingula of the lung, which can either displace the IMA medially or herniate under the IMA, causing a kink at the anastomosis. To prevent these complications, the IMA pedicle should be harvested sufficiently in the cephalad direction so that it does not "hang down" from a second intercostal space tethering. To keep the anastomosis from adhering to the chest wall incision, the previously mobilized extrapericardial fat can be placed anterior to the anastomosis. Additionally, a generous lateral incision into the pericardium should be made to allow unobstructed entry of the IMA pedicle into the mediastinal space. This "window" can be approximated anteriorly by the mediastinal fat.



8 After the distals are completed, the balloon is deflated and withdrawn from the arterial cannula in preparation for construction of a proximal anastomosis. Because of the size of the incision, the orientation and lengths of the grafts must be closely scrutinized. Once all grafts are cut and oriented, a partial occlusion clamp is applied to the aorta under low flow. Traction on previously placed pericardial sutures in the veil of the pericardium defining the transition of the superior vena cava to an extrapericardial structure greatly enhances the surgeon's ability to gain control of the aorta.



9 Standard aortotomy punches are used to create the sites for the proximal anastomosis.



10 Specially designed single-action long needle drivers greatly facilitate the anastomosis. The grafts are de-aired, and reperfusion through the completed grafts is established. Meticulous hemostasis at the distal anastomoses should be verified before the patient is weaned from cardiopulmonary bypass. Indeed, when completing a distal anastomosis, cardioplegia is given not only to augment protection, but also to ensure graft runoff and anastomotic integrity. It is very difficult to re-explore graft sites via the small thoracotomy once the patient is off bypass.

POSTOPERATIVE CARE

Because PACABG aims to provide the reliability of surgical revascularization with a less invasive approach for the patient, postoperative pain is addressed in the operating room. Local infiltration of the wound with 0.5% bipuvicaine is performed to relieve early discomfort.

Unless contraindicated, patients are placed on a rapid ventilator weaning program that results in extubation within 4 hours. Early in our clinical experience, patients were extubated in the operating room; this has not proved advantageous and extends valuable operating room time. Patients are mobilized early and diuresed to speed recovery. Restrictions after hospital discharge in uncomplicated cases are few, as patients are allowed to resume driving and most household duties within 1 to 2 weeks.

RESULTS AND CONCLUSIONS

PACABG aims to preserve the anastomotic reliability of conventional CABG while making the procedure easier on the patient. Angiographic data are available from various investigators. Ribakove reported the first series in 1997.[3] Predischarge angiograms were performed in

37 patients undergoing primary CABG. All graft patency was 97.7%. Patency of the LIMA to the LAD was 100%. Other investigators have reported angiographic data, as summarized in Table 1. These patency rates compare favorably with conventional CABG graft survival rates. The most comprehensive data for conventional CABG come from Lytle. At a mean of 15 months, graft patency was 97.3% for the LIMA to LAD and 84% for all grafts.[6]

A voluntary registry was established early to accumulate outcome data regarding PACABG cases. The database is industry supported, maintained by an independent research facility, and monitored by a steering committee of cardiac surgeons. In the first manuscript summarizing the data from the registry, Galloway reported low risk of adverse outcomes in patients undergoing PACABG.[7] Operative mortality was observed in 1% of patients. Likewise, rates of other major perioperative morbidity were low. These data are summarized in Table 2. The multi-institutional nature of the data and the relatively large number of patients led the authors to conclude that PACABG is a safe alternative to standard CABG. Criticism of the report noted that the patients were relatively low risk and that no significant risk stratification was performed. A multi-institutional trial reported by Grossi[8] reviewed risk-adjusted mortality and morbidity. This report reviewed the results of more than 300 consecutive PACABG operations from three institutions. All 3 centers participated in The Society of Thoracic Surgery (STS) database, a voluntary database supported and maintained by the STS. Thirty-day results for major morbidity and mortality were compared with risk-adjusted results from the STS database. Mortality was 0.99%, with a predicted risk of 1.17%. The most significant complication was bleeding necessitating reoperation (3.3%). The high rate of re-exploration was related to early inexperience with the procedure.

To more closely compare the results between PACABG and conventional CABG, Groh reported results of a population risk-matched study.[9] The first 229 consecutive PACABG patients were risk-matched with patients undergoing conventional CABG simultaneously at 1 institution. The STS risk score was used to match the 2 groups. The risk score uses 35 weighted variables to assess the perioperative risk. The observed mortality rate was lower than expected for both groups: 0.9% observed versus 1.3% expected, and for conventional CABG, and 0.9% observed versus 1.3% expected for PACABG. Perioperative adverse outcomes were insignificantly different between the two groups. However, the risk of perioperative transfusion was significantly lower in the PACABG group. In addition, the postoperative length of stay was significantly shorter in the PACABG group; the PACABG group had a median postoperative length of stay of 1-½ days shorter than patients undergoing sternotomy.

To date, the vast majority of PACABG procedures have been performed on low-risk patients. The rate of perioperative complications is similar in risk-stratified groups undergoing PACABG and conventional CABG. In these low-risk patients, shorter hospitalizations and the decreased need for transfusions have been appreciated. Future work needs to focus on the patient selection process. A vast array of different mechanical revascularization strategies is available for our patients. New surgical options for performance of the revascularization procedure such as the "off-pump" CABG and PACABG appear to have specific advantages for some patient groups.

In our practice, PACABG has evolved into being performed primarily for patients who require 1 to 3 grafts, with good target coronary arteries, and who are at low risk for a complication of cardiopulmonary bypass. Patients at high risk for complications are managed with an off-pump strategy. Patients who do not fit a profile based on body habitus, coronary anatomy, distal disease assessment, or perfusion issues that are favorable for PACABG are managed with standard open CABG. Arrested heart surgery provides the best and most predictable environment for performing the distal anastomosis in patients at low risk for complications of cardiopulmonary bypass. The challenge facing coronary surgeons today is to offer the most

Table 1. Patency in Port-Access CABG

Study	Patency (%)	Angiogram Performed	No. of Patients
Galloway et al[10]	100, LIMA-LAD 96, overall	Postoperative	42
Reichanspurner et al[11]	100 97	Intraoperative 3 months postoperative	10 28
Ribakove et al[12]	100, LIMA-LAD 98 overall	Before discharge	27
Barlow et al[13]	100, LIMA LAD	12 weeks postoperative	10
Vigano et al[14]	97.6	Postoperative	20

Abbreviation: LIMA-LAD, left internal mammary artery–left anterior descending.

Table 2. Morbidity and Mortality of Patients Who Underwent CABG (n = 583)

Outcome	% of Patients
Death	1.0
Stroke	2.2
Myocardial infarction	1.0
New-onset afibrillation	5.0
Reoperation for primary procedure	0.0
Reoperation for other chest procedure	1.5
Multiorgan failure	0.0
Renal failure	0.2

Data from Galloway et al.[10]

advantageous operation for each patient based on that patient's specific risks and needs.

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