Dedication

To my parents, Leah and Samuel Bojar, who instilled in me a lifelong desire for learning, the importance of sharing knowledge, and a dedication to provide all patients with the best possible care.
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The future of cardiac surgery faces significant challenges with the widespread application of transcatheter technologies, including coronary stenting, percutaneous valves, endovascular approaches to thoracic aortic disease, and ablation of arrhythmias in the electrophysiology laboratory. Most of these technologies evolved from the concept that a less invasive approach to structural heart disease is preferred by patients to reduce trauma, minimize complications, expedite recovery, and improve the quality of life.

Although these approaches may be applicable to patients at both ends of the clinical spectrum, surgery will still remain the best approach for many patients – especially those with advanced cardiac disease and significant noncardiac issues. Although less invasive surgery is seeing wider applicability, most surgical procedures require use of cardiopulmonary bypass with its inherent morbidity. There is little doubt that surgical patient acuity continues to increase, and excellence in perioperative care will remain essential to optimizing surgical results, no matter which surgical technique is used. This has become especially important with the increasing demand for transparency, with the perception that outcomes are directly related to the quality of care. Thus, it has become essential that surgical programs maintain the highest level of care to remain competitive.

The 5th edition of the Manual has been completely updated to provide current approaches to patient care. The reference lists have also been extensively updated to direct the reader to some of the best resources available on most topics. I am hopeful that this 5th edition will provide a comprehensive up-to-date review that will assist healthcare providers in delivering the best possible care to their cardiac surgical patients.

Robert M. Bojar, MD
Worcester, MA
December 2010
Acknowledgments

Cardiac surgery requires meticulous attention to detail to ensure the best possible surgical result. Decision-making in the perioperative period involves close cooperation and communication among all members of the healthcare team, including cardiac surgeons, anesthesiologists, physician assistants, nurse practitioners, and critical care and floor nurses. Identifying problems and seeking consultations with experts in other fields is important to ensure optimal outcomes. I am greatly appreciative of the efforts of many individuals who set aside valuable time to review sections of the manuscript in their areas of expertise. I would like to acknowledge the assistance of David Liu, MD, Gary Noroian, MD, Timothy Hastings, CRNA, Bettina Alpert, CCP, Kathi O’Leary, CCP, and Wanda Reynolds, CCRT, for their review and comments. I am especially indebted to George Gordon, MD, whose vast knowledge of anesthesiology, echocardiography, pharmacology, and physiology allowed him to provide insight and suggestions on multiple areas of clinical management. Lastly, I am indebted to my Chief Physician Assistant, Theresa Phillips, PA, who helps coordinate the care my patients receive, and who reviewed many sections of the manuscript to ensure their accuracy.
Notice: The indications and dosages of all drugs in this book have been recommended in the medical literature and conform to the practices of the general community. The medications described do not necessarily have specific approval by the Food and Drug Administration for use in the diseases and dosages for which they are recommended. The package insert for each drug should be consulted for use and dosage as approved by the FDA. Because standards for usage change, it is advisable to keep abreast of revised recommendations, particularly those concerning new drugs. Although the author has made every attempt to ensure the accuracy of drug dosages, it is the obligation of the reader to confirm drug dosages prior to prescribing any drug.

Abbreviations used through this book are typeset and easy to read. However, many hospitals have lists of approved abbreviations designed to prevent medication errors, which are often caused by inability to interpret handwriting. It is therefore advisable that all orders be written according to individual hospital regulations to ensure that accurate medication doses and intervals are provided to patients.
CHAPTER 1

Synopsis of Adult Cardiac Surgical Disease

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It is essential that all individuals involved in the assessment and management of patients with cardiac surgical disease have a basic understanding of the disease processes that are being treated. This chapter presents the spectrum of adult cardiac surgical disease that is encountered in most cardiac surgical practices. The pathophysiology, indications for surgery, specific preoperative considerations, and surgical options for various diseases are presented. Diagnostic techniques and general preoperative considerations are presented in the next two chapters. Issues related to cardiac anesthesia and postoperative care specific to most of the surgical procedures presented in this chapter are discussed in Chapters 4 and 8, respectively. The most current guidelines for the evaluation and management of patients with cardiac disease can be obtained from the American College of Cardiology website (www.acc.org).

I. Coronary Artery Disease

A. Pathophysiology. Coronary artery disease (CAD) results from progressive blockage of the coronary arteries by atherothrombotic disease. Significant risk factors include hypertension, dyslipidemia (especially high LDL and low HDL levels), diabetes mellitus, cigarette smoking, and obesity. Clinical syndromes result from an imbalance of oxygen supply and demand resulting in inadequate myocardial perfusion to meet metabolic demand (ischemia). Progressive compromise in luminal diameter producing supply/demand imbalance usually produces a pattern of chronic stable angina. Plaque rupture with superimposed thrombosis is responsible for most acute coronary syndromes (ACS), which include classic “unstable angina”, non-ST-elevation myocardial infarctions (NSTEMI), and ST-elevation infarctions (STEMI). Interestingly, plaque rupture commonly occurs in coronary segments that are not severely stenotic. Endothelial dysfunction has become increasingly recognized as a contributing factor to worsening ischemic syndromes. Generalized systemic inflammation, indicated by elevated C-reactive protein levels, is usually noted in patients with ACS, and appears to be associated with adverse outcomes.1

B. Management strategies

1. Symptomatic coronary disease is initially treated with medical therapy, including aspirin, nitrates, and β-adrenergic blockers. Calcium channel blockers (CCBs) are considered if β-blockers are contraindicated. Statins should be given to control dyslipidemias and are effective for plaque stabilization. Angiotensin-converting
enzyme (ACE) inhibitors are used for control of hypertension, especially in patients with compromised left ventricular function. Clopidogrel generally does not provide benefit to patients with chronic stable angina, except in selected subsets, but is beneficial in patients with an ACS.2–6

2. STEMI is preferentially treated by percutaneous coronary intervention (PCI) (angioplasty and stenting), although thrombolytic therapy may be considered when PCI cannot be performed within a few hours. Clinical benefit is time-related (“time is myocardium”), and the best results are obtained with “door to balloon” times less than 90 minutes. However, myocardial salvage may still occur if reperfusion can be accomplished within 6 hours of the onset of chest pain.7,8

3. Patients presenting with an ACS should be treated with aspirin and unfractionated or low-molecular-weight heparin (LMWH), as well as the standard therapy listed above (nitrates, β-blockers, statins).9,10 Clopidogrel may provide clinical benefit to these patients if they are to be treated medically, and it may be given if an early invasive strategy is proposed. The 2007 ACC/AHA recommendations were that it should not be given if urgent surgery is considered likely, but this can be difficult to predict and therefore it is given routinely. Most studies have shown that 30-day outcomes are better in patients undergoing coronary artery bypass graft (CABG) surgery who initially received clopidogrel.2–5 However, one study showed that there was no difference in outcomes whether clopidogrel was given or not if patients had surgery within 5 days, but outcome was better if it was initially given on presentation, then stopped for at least 5 days before surgery.11 This study supports the ACC/AHA recommendation that clopidogrel be stopped at least 5 days before surgery except in urgent or emergent situations.9 If prasugrel is given in anticipation of PCI, but CABG is recommended instead, it should be stopped at least 7 days prior to surgery.

4. In patients with continuing ischemia and high-risk features (crescendo angina over 48 hours, rest pain, ECG changes at rest, congestive heart failure [CHF], hemodynamic instability, or an elevated troponin level), platelet glycoprotein IIb/IIIa inhibitors, such as tirofiban or eptifibatide, may be added to the regimen with plans to proceed to an early invasive strategy of catheterization. At that time, the appropriate means of intervention (PCI vs. CABG) can be determined. If a IIb/IIIa inhibitor is used and a clopidogrel load is not given prior to PCI, it will provide antiplatelet activity until the initial dosing of clopidogrel achieves adequate platelet inhibition (a few hours after a 600 mg load). Numerous trials are evaluating the role of various platelet inhibitors and the use of bivalirudin rather than heparin during PCI.

C. Selection of an interventional procedure

1. An assessment of the patient’s clinical presentation, the extent and nature of coronary disease, degree of inducible ischemia on stress testing, and status of ventricular function are taken into consideration when determining whether the patient is an appropriate candidate for an interventional procedure.12 In patients with convincing evidence of an ACS, stress tests are not indicated prior to cardiac catheterization. The primary objective of any intervention is the relief of ischemia to prevent or minimize the extent of myocardial damage.

2. PCI has seen wide applicability beyond its proven benefit in early randomized trials, which generally had very selective inclusion criteria. It is often preferable to surgery in patients presenting with STEMI or with ongoing ischemia with NSTEMI because
it can more promptly salvage myocardium – unless the anatomy is such that CABG is preferable (see below). The benefits of PCI in patients with chronic stable angina are not as well defined.\textsuperscript{13,14}

3. The indications for PCI in multivessel disease are controversial. Although several studies suggest that CABG improves long-term survival better than PCI, other trials indicate that survival is comparable, although more patients undergoing PCI require reintervention.\textsuperscript{15–20} The rationale is that PCI only addresses focal lesions despite CAD being a multifocal disease, whereas CABG bypasses the entire proximal segment. Thus, repeat intervention, usually in sites other than the original stent location, is much more likely if PCI is utilized. Evidence-based guidelines have been established by major organizations to identify when PCI and/or CABG is indicated (Figures 1.1 and 1.2).\textsuperscript{12} These guidelines will continue to evolve when the results of additional trials including multivessel and left main disease,\textsuperscript{21–23} reoperative situations, varying patient subpopulations, and newer stent technologies become available. One approach to decision making is use of the SYNTAX score (accessible at www.syntaxscore.com), which assesses the extent and nature of coronary artery disease and provides comparative major adverse cardiac event (MACE) rates for PCI and CABG for multivessel as well as left main disease.\textsuperscript{23–25} Use of such data can provide patients with adequate evidence-based clinical information to give informed consent for any interventional procedure.

4. Although drug-eluting stents (DES) are associated with a lower risk of restenosis than bare-metal stents (BMS), most studies have not shown a significant impact on the risk of myocardial infarction or death.\textsuperscript{26} In fact, the risk of stent thrombosis is greater with DES, and this is accentuated in patients who are resistant to the antiplatelet effects of aspirin and/or clopidogrel.\textsuperscript{27} Platelet function testing may be beneficial in determining which patients are resistant to their antiplatelet effects. To minimize the risk of stent thrombosis, it is recommended that patients receiving BMS take aspirin and clopidogrel for at least 1 month, and those receiving DES take these medications for at least 1 year.\textsuperscript{28}

5. One should not consider either PCI or CABG an exclusive approach to a patient’s coronary artery disease. For example, one hybrid approach is to perform a PCI of the culprit lesion in an unstable patient in the interest of myocardial salvage and then refer the patient for surgical revascularization of other lesions.\textsuperscript{29} It has even been proposed that placing a left internal thoracic artery (LITA) to the left anterior descending artery (LAD) in a patient with three-vessel disease provides the essential long-term benefit of a CABG and converts the patient’s anatomy to two-vessel disease which can be managed medically or with PCI.\textsuperscript{30}

D. Indications for surgery. The justification for proceeding with an intervention is based primarily upon an assessment of whether the patient is at increased risk for an adverse cardiac event. Studies have shown that surgery is very effective in relieving angina, in many cases is able to delay infarction, and in most cases can improve survival compared with continued medical management. CABG can be deemed appropriate based on an assessment of the patient’s symptom status, non-invasive imaging studies, and the degree of anatomic disease (Figure 1.1).\textsuperscript{12} It should be considered when PCI is not feasible or when the short- and long-term benefits of CABG are superior to those of PCI (Figure 1.2).
### SYNOPSIS OF ADULT CARDIAC SURGICAL DISEASE

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#### Coronary Anatomy
- **Asymptomatic**
  - CTO of 1 vz.: no other disease
  - 1-2 vz. disease; no Prox. LAD
  - 1 vz. disease; of Prox. LAD
  - 2 vz. disease with Prox. LAD
  - 3 vz. disease; no Left Main

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#### Coronary Anatomy
- **CCS Class I or II Angina**
  - CTO of 1 vz.: no other disease
  - 1-2 vz. disease; no Prox. LAD
  - 1 vz. disease; of Prox. LAD
  - 2 vz. disease with Prox. LAD
  - 3 vz. disease; no Left Main

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#### Coronary Anatomy
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  - 2 vz. disease with Prox. LAD
  - 3 vz. disease; no Left Main
Clinical scenarios. The patient with refractory angina or a large amount of myocardium in ischemic jeopardy has an indication for an intervention relatively independent of the extent of coronary involvement:

a. Class III–IV chronic stable angina refractory to medical therapy
b. Acute coronary syndromes, including unstable angina and NSTEMIs
c. Acute ischemia or hemodynamic instability following attempted PCI, which may include dissection and compromised flow or coronary perforation with tamponade
d. Acute evolving STEMI within 4–6 hours of the onset of chest pain or later if there is evidence of ongoing ischemia (early postinfarction ischemia)
e. Markedly positive stress test prior to major intra-abdominal or vascular surgery—but not necessarily if the patient has chronic stable angina
f. Ischemic pulmonary edema

Anatomy. A second group of patients includes those without disabling angina or refractory ischemia in whom the extent of coronary disease, the status of ventricular function, and the degree of inducible ischemia on stress testing are such that surgery may improve long-term survival. This is presumed to occur by preventing infarction and preserving ventricular function. Surgery is especially beneficial for patients with impaired ventricular function and inducible ischemia, in whom the medical prognosis is unfavorable. The following recommendations for surgery, based on the randomized controlled trials of primarily chronic stable angina in the early 1980’s have been incorporated into the 2009 appropriateness criteria guidelines noted in Figure 1.2. For patients with ACS, they are all class I indications for surgery, and for patients

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Figure 1.2 • Recommended method of revascularization based on extent of coronary disease. A, appropriate; U, uncertain; I, inappropriate. (Reproduced with permission from Patel et al., J Am Coll Cardiol 2009;53:530–53.)

1. Clinical scenarios. The patient with refractory angina or a large amount of myocardium in ischemic jeopardy has an indication for an intervention relatively independent of the extent of coronary involvement:

a. Class III–IV chronic stable angina refractory to medical therapy
b. Acute coronary syndromes, including unstable angina and NSTEMIs
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f. Ischemic pulmonary edema

2. Anatomy. A second group of patients includes those without disabling angina or refractory ischemia in whom the extent of coronary disease, the status of ventricular function, and the degree of inducible ischemia on stress testing are such that surgery may improve long-term survival. This is presumed to occur by preventing infarction and preserving ventricular function. Surgery is especially beneficial for patients with impaired ventricular function and inducible ischemia, in whom the medical prognosis is unfavorable. The following recommendations for surgery, based on the randomized controlled trials of primarily chronic stable angina in the early 1980’s have been incorporated into the 2009 appropriateness criteria guidelines noted in Figure 1.2. For patients with ACS, they are all class I indications for surgery, and for patients

---

Figure 1.1 • Appropriateness ratings for coronary artery bypass grafting. The grid incorporates Canadian Cardiovascular Society (CCS) class, extent of coronary disease, and results of non-invasive testing in determining whether CABG is an appropriate procedure. A, appropriate; U, uncertain; I, inappropriate. (Reproduced with permission from Patel et al., J Am Coll Cardiol 2009;53:530–53.)
with fewer symptoms or moderate degrees of ischemia, they are class IIa and IIb indications (see Appendix 1).

a. Left main stenosis >50%

b. Three-vessel disease with ejection fraction (EF) <50%

c. Three-vessel disease with EF >50% and significant inducible ischemia on stress testing

d. Two-vessel disease with involvement of proximal LAD and EF <50% or significant inducible ischemia on stress testing

e. One- and two-vessel disease not involving the LAD with extensive myocardium in jeopardy but lesions not amenable to PCI

Although surgery is appropriate in these patients, most patients with one- or two-vessel disease are preferentially treated by PCI. Furthermore, although the 2009 guidelines consider PCI for left main disease to be “inappropriate” and for three-vessel disease to be “uncertain”, use of the SYNTAX score, the Mayo Clinic risk score, and other risk models for PCI may modify this approach.23–25

3. Other conditions. A third group of patients should undergo bypass surgery for coronary stenoses exceeding 50% when other open-heart procedures are indicated:

a. Valve operations, septal myectomy, etc.

b. Surgery for postinfarction mechanical defects (left ventricular aneurysm, ventricular septal rupture, acute mitral regurgitation)

c. Coronary artery anomalies with risk of sudden death (vessel passing between the aorta and pulmonary artery)

E. Preoperative considerations

1. Preoperative autologous blood donation has been considered to reduce the requirement for homologous transfusion. This may be feasible in patients with chronic stable angina, but not in those with acute coronary syndromes or left main disease. With the increasing safety of blood, the use of antifibrinolytic drugs, and the performance of off-pump surgery, this is no longer a common practice.31

2. Anemia. Preoperative blood transfusions should be considered in patients with an ACS and a hematocrit <28%. This may not only improve the ischemic syndrome but will minimize hemodilution during surgery. Low preoperative hematocrits may increase operative mortality following CABG, often because of an association with other adverse risk factors for mortality, and it is not known whether transfusions can reduce that risk.32 Certainly, indiscriminate use of transfusions must be avoided because of their association with adverse outcomes following cardiac surgery.33–35

a. In addition to blood withdrawal for preoperative lab tests, it is not uncommon for the hematocrit to fall several points after a cardiac catheterization from both blood loss and hemodilution with hydration. One study showed that coronary angiography was associated with a fall in hemoglobin of 1.8 g/dL (equivalent to about a 5.4% fall in hematocrit).36

b. Hemodilution on cardiopulmonary bypass (CPB) to a hematocrit <20% may be associated with an increased risk of renal dysfunction, stroke, optic neuropathy, and death.37–40 Low hematocrits lower oncotic pressure and viscosity, increase fluid requirements, which contributes to extracellular edema, and make it more difficult to maintain an adequate blood pressure during and after CPB. Patients with
profound anemia tend to bleed and require more blood component transfusions. Thus, preoperative transfusions to an adequate level may be considered to reduce patient morbidity, possibly reduce the overall number of transfusions required intra- and postoperatively, and potentially decrease mortality.

3. Ischemia. Aggressive management of ongoing or potential ischemia is indicated in patients with critical coronary disease to reduce surgical risk. This may include adequate sedation and analgesia, antiischemic medications to control heart rate and blood pressure (intravenous nitrates and β-blockers), antiplatelet and anticoagulant medications (aspirin, clopidogrel, heparin, IIb/IIIa inhibitors), and/or placement of an intra-aortic balloon pump (IABP) for refractory ischemia. It cannot be overemphasized that just because a patient has been catheterized and accepted for surgery does not mean that medical care should not be aggressive up to the time of surgery! If the patient has persistent ischemia despite all of these measures, emergency surgery is mandatory.

a. All antianginal medications should be continued up to and including the morning of surgery. Studies have demonstrated the benefit of preoperative β-blocker therapy in lowering perioperative mortality in cardiac surgery patients.41 Patients being admitted the morning of surgery should be reminded to take their medications before coming to the hospital.

b. Unfractionated heparin (UFH) is often used in patients with acute coronary syndromes, left main coronary disease, or a preoperative IABP. The heparin should generally be continued up to the time of surgery. Central lines can usually be placed safely while the patient is heparinized. Patients receiving heparin should have their platelet count rechecked daily to be vigilant for the development of heparin–induced thrombocytopenia (HIT). Note that preoperative assessment for HIT antibodies is not indicated in the absence of a clinical indication.42

c. Low-molecular-weight heparin (LMWH) is often used in patients presenting with an ACS and may be used in the cath lab as well. It must be stopped at least 18–24 hours prior to surgery to minimize the risk of perioperative bleeding. Fondaparinux, often used routinely for venous thromboembolism prophylaxis, has a half-life of 17–21 hours and must be stopped at least 48 hours prior to surgery.

d. Aspirin is routinely used in patients with known coronary disease or given upon presentation to the hospital. Platelet function generally returns to normal within 3 days of cessation of aspirin, so it can be stopped at that time for truly elective cases.43,44 Otherwise, aspirin 81 mg should be continued up to the time of surgery in patients with an ACS or critical coronary disease, since it may improve outcomes without a significant increase in the risk of bleeding.44–47

e. Preoperative use of clopidogrel has generally been shown to significantly increase the risk of bleeding and reexploration for bleeding.5,44,47,48 Thus, it has been recommended that it should be stopped 5–7 days before elective surgery, although stopping it for only 3 days may be acceptable prior to off-pump surgery.49 Prasugrel is a more potent ADP inhibitor that can achieve 80% platelet inhibition within 30 minutes of administration. Because of its effectiveness and comparable half-life to clopidogrel, it may contribute to an even greater risk of perioperative bleeding and should be stopped at least 7 days prior to surgery, if possible.
A loading dose of clopidogrel (300–600 mg) is frequently given to patients presenting with an ACS in the emergency room or in preparation for a PCI. Alternatively, a loading dose of prasugrel (60 mg) may be given in the cath lab. If PCI is not feasible or fails, the patient will then be at higher risk for bleeding following CABG.

In some cases, emergency stenting of a culprit lesion causing an evolving infarction may be performed with subsequent referral for urgent surgery to achieve complete revascularization. In this situation, it is preferable to use a IIb/IIIa inhibitor to minimize stent thrombosis as a bridge to surgery. It should be stopped 4 hours prior to surgery, so that by the time surgery starts, 80% of platelet activity will have recovered.

In patients with prior stenting (<1 month for a BMS and <1 year for a DES), there is an increased risk of stent thrombosis if clopidogrel is stopped. Either surgery must be performed with the patient still taking clopidogrel or one might possibly stop the clopidogrel for only 3 days to have some residual protective antiplatelet activity, yet hopefully less intraoperative bleeding.

Other preoperative medications to be considered

- **Amiodarone** is beneficial in reducing the incidence of postoperative atrial fibrillation (AF). One respected randomized trial showed a benefit to giving 10 mg/kg daily starting 6 days prior to surgery, although a shorter course may be just as effective.

- **Statins** have been demonstrated to reduce operative mortality, the risk of stroke, and the occurrence of AF when used in high doses (atorvastatin 40 mg).

- **Steroids** have been evaluated as a means of reducing the systemic inflammatory response of surgery and have been shown to improve myocardial function and possibly reduce the incidence of AF. However, improvement in pulmonary function has not been clearly shown, and steroids do worsen postoperative hyperglycemia. Since the benefits are controversial, steroids have not seen widespread usage.

**Surgical procedures**

1. **Traditional coronary artery bypass grafting** is performed through a median sternotomy incision with use of CPB. Myocardial preservation is usually provided by cardioplegic arrest. The procedure involves bypassing the coronary blockages with a variety of conduits. The left internal thoracic (or mammary) artery (ITA) is usually used as a pedicled graft to the LAD and is supplemented by either a second ITA graft or radial artery graft to the left system and/or saphenous vein grafts interposed between the aorta and the coronary arteries (Figure 1.3).

   - The saphenous vein should be harvested endoscopically to minimize patient discomfort, reduce the incidence of leg edema and wound healing problems, and optimize cosmesis. There are some concerns that endoscopic harvesting could produce endothelial damage that might compromise long-term patency and reduce long-term survival.

   - Use of additional arterial conduits (bilateral ITAs, radial artery) can be recommended to improve event-free survival, although one study of statin use showed comparable survival of patients receiving one or two ITAs. The radial artery can be harvested endoscopically using a tourniquet to minimize bleeding.
during the harvest with placement of a drain afterwards to prevent blood accumulation within the tract.\textsuperscript{65–67} With radial artery grafting, a vasodilator is initiated during surgery to minimize spasm (either IV diltiazem 0.1 mg/kg/h (usually 5–10 mg/h) or IV nitroglycerin 10–20 µg/min (0.1–0.2 µg/kg/min).\textsuperscript{68} This is continued in the ICU and then converted to either amlodipine 5 mg po qd or Imdur 20 mg po qd for several months. The benefit of such pharmacologic management to prevent spasm has been universally accepted, but not proven.

2. Concerns about the adverse effects of CPB spurred the development of “off-pump” coronary surgery (OPCAB), during which complete revascularization should be achieved with the avoidance of CPB. Deep pericardial sutures and various retraction devices are used to position the heart for grafting without hemodynamic compromise. A stabilizing platform minimizes movement at the site of the arteriotomy (Figure 1.4). Intracoronary or aortocoronary shunting can minimize ischemia after an arteriotomy is performed.\textsuperscript{69}

a. Conversion to on-pump surgery may be necessary in the following circumstances:
   i. Coronary arteries are very small, severely diseased or intramyocardial.
   ii. LV function is very poor, or there is severe cardiomegaly or hypertrophy that precludes adequate cardiac translocation without hemodynamic compromise or arrhythmias.
   iii. The heart is extremely small and vertical in orientation.
iv. Uncontrollable ischemia or arrhythmias develop with vessel occlusion that persists despite distal shunting.

v. Intractable bleeding occurs that cannot be controlled with vessel loops or an intracoronary shunt.

b. OPCABs reduce transfusion requirements, and arguably lower mortality and reduce the risk of stroke, renal dysfunction, and atrial fibrillation.\textsuperscript{70–73} Despite these potential advantages, enthusiasm for this technique is modest, and it is estimated that fewer than 20% of CABGs are performed off-pump. Many surgeons reserve its use for patients with limited disease. Its major advantage may be in the very high-risk patient with multiple comorbidities in whom it is critical to avoid CPB.

c. In some patients with severe ventricular dysfunction, the heart will not tolerate the manipulation required during off-pump surgery. In this circumstance, right ventricular assist devices can be used to improve hemodynamics. Alternatively, surgery can be done on-pump on an empty beating heart to avoid the period of cardioplegic arrest. This technique may be beneficial in patients with ascending aortic disease that prevents safe aortic cross-clamping, but does allow for safe cannulation and use of aortic punches, such as the HEARTSTRING proximal seal system (Maquet Cardiovascular), to perform the proximal anastomoses.

3. **Minimally invasive direct coronary artery bypass (MIDCAB)** involves bypassing the LAD with the LITA without use of CPB via a short left anterior thoracotomy incision.\textsuperscript{74} An additional incision in the right chest can be used to bypass the right coronary artery. Combining a LITA to the LAD with stenting of other vessels (“hybrid” procedure) has also been described.\textsuperscript{29,30}
4. **Robotic** or totally endoscopic coronary artery bypass (TECAB) can be used to minimize the extent of the surgical incisions and reduce trauma to the patient. Robotics can be used for both ITA takedown and grafting to selected vessels through small ports. These procedures can be done without CPB or using CPB with femoral cannulation. Generally, TECAB is used for limited grafting, but wider applicability is certainly feasible.\(^7^5\)

5. **Transmyocardial revascularization (TMR)** is a technique in which laser channels are drilled in the heart with CO\(_2\) or holmium-YAG lasers to improve myocardial perfusion. Although the channels occlude within a few days, the inflammatory reaction created induces neoangiogenesis that may be associated with upregulation of various growth factors, such as vascular endothelial growth factor. This procedure can be used as a sole procedure performed through a left thoracotomy for patients with inoperable CAD in regions of viable myocardium. Alternatively, it can be used as an adjunct to CABG in viable regions of the heart where bypass grafts cannot be placed.\(^7^6\)

### II. Left Ventricular Aneurysm

**A. Pathophysiology.** Occlusion of a major coronary artery may produce extensive transmural necrosis which converts muscle into thin scar tissue. This results in formation of a left ventricular aneurysm (LVA) which exhibits dyskinesia during ventricular systole. In contrast, early reperfusion of an occluded vessel may limit the extent of myocardial damage with preservation of epicardial viability, resulting in an area of akinesia. This will result in an ischemic cardiomyopathy with a dilated ventricle that remodels with altered spherical geometry but does not produce an aneurysm.

**B. Presentation.** The most common presentation of LVAs and ischemic cardiomyopathies is CHF due to systolic dysfunction. With LVAs, there is a reduction of stroke volume caused by geometric remodeling of the aneurysmal segment due to loss of contractile tissue and an increase in ventricular dimensions. Angina may also occur due to the increased systolic wall stress of a dilated ventricle and the presence of multivessel CAD. Systemic thromboembolism may result from thrombus formation within the dyskinetic or akinetic segment. Malignant ventricular arrhythmias or sudden death may result from the development of a macroreentry circuit at the border zone between scar tissue and viable myocardium.

**C. Indications for surgery.** Surgery is usually not indicated for the patient with an asymptomatic aneurysm because of its favorable natural history. This is in contrast to the unpredictable prognosis and absolute indication for surgery in a patient with a false aneurysm, which is caused by a contained rupture of the ventricular muscle. Surgery may be beneficial in the asymptomatic patient with an extremely large aneurysm or when extensive clot formation is present within the aneurysm. Surgery is most commonly indicated to improve symptoms and prolong survival when one of the four clinical syndromes noted above (angina, CHF, embolization, or arrhythmias) is present. Arrhythmias may be treated by a non-guided endocardial resection through the aneurysm with/without cryosurgery along with subsequent placement of a transvenous implantable cardioverter-defibrillator (ICD).

**D. Preoperative considerations**

1. A biplane left ventriculogram is helpful in identifying regions of akinesia and dyskinesia and assessing the function of noninfarcted segments. Echocardiography
is best for assessing ventricular size and dimensions, wall motion of the noninfarcted segments, the presence of thrombus, and mitral valve function, which is often abnormal with dilated cardiomyopathies.

2. The patient should be maintained on heparin up to the time of surgery if left ventricular thrombus is present.

E. Surgical procedures

1. Standard aneurysmectomy entails a ventriculotomy through the aneurysm, resection of the aneurysm wall, including part of the septum if involved, and linear closure over felt strips (Figure 1.5).\textsuperscript{77}

![Figure 1.5](image_url)

**Figure 1.5** - Repair of a left ventricular aneurysm using the linear closure technique. (A) The thinned-out scar tissue is opened and partially resected. Any left ventricular thrombus is removed. (B) The aneurysm is then closed with mattress sutures over felt strips. (C) An additional over-and-over suture is placed over a third felt strip. (D) Cross-section of the final repair.
2. Endoventricular reconstruction techniques are applicable to large aneurysms or akinetic segments with the intent of reducing ventricular volume and restoring an elliptical shape.

a. The “endoaneurysmmorrhaphy” technique is used for large aneurysms. A pericardial or Dacron patch is sewn to the edges of viable myocardium at the base of the aneurysm and the aneurysm wall is reapproximated over the patch (Figure 1.6). This preserves left ventricular geometry and improves ventricular function to a greater degree than the linear closure method.

b. A slightly more elaborate endoventricular reconstruction involves the endoventricular circular patch plasty technique of Dor, which is termed “surgical ventricular restoration” (SVR). This can be applied to left ventricular aneurysms as well as cases of ischemic cardiomyopathy with anterior akinesis (Figure 1.6D). The procedure involves placement of an encircling suture at the junction of the contracting and noncontracting segments, and then

Figure 1.6 • Repair of a left ventricular aneurysm using the endoaneurysmmorrhaphy technique. (A,B) A pericardial patch is sewn at the base of the defect at the junction of scar and normal myocardium to better preserve ventricular geometry. The resected edges of the left ventricle are closed in a similar fashion to the linear technique. (C) Cross-section of the final repair. (D) The Dor procedure is a modification of this technique in which a circumferential pursestring suture is placed at the base of the defect to restore a normal orientation to the ventricle. A patch is then sewn over the defect.
exclusion of the noncontracting segment with a patch. This produces an elliptical contour of the heart and results in significant improvement in ventricular size and function. This procedure is generally done on a beating heart to allow for better differentiation of akinetic and normal segments of the heart.

c. Although SVR is associated with a reduction in LV volume, clinical improvement is not uniform. Several studies have suggested that the addition of SVR to a CABG improves clinical status and long-term survival.80,81 However, the STICH trial of patients with CAD-related anterior akinesia or dyskinesia with EF <35% was unable to demonstrate that reduction in LV size was associated with an improvement in symptoms or a reduction in mortality after 4 years (see also page 62).82

3. Coronary bypass grafting of critically diseased vessels should be performed. Bypass of the LAD and diagonal arteries should be considered if septal reperfusion can be accomplished.

4. Mitral valve repair with a complete annuloplasty ring is indicated when the severity of mitral regurgitation (MR) is 2+ or greater. MR is usually related to apical tethering of the leaflets due to ventricular dilatation or may result from annular dilatation.

III. Ventricular Septal Rupture

A. Pathophysiology. Extensive myocardial damage subsequent to occlusion of a major coronary vessel may result in septal necrosis and rupture. This usually occurs within the first week of an infarction, more commonly in the anterolateral region (from occlusion of the left anterior descending artery), and less commonly in the inferior wall (usually from occlusion of the right coronary artery). It is noted in fewer than 1% of acute MIs, and the incidence has been reduced by use of early reperfusion therapy for STEMI. The presence of a ventricular septal defect (VSD) is suggested by the presence of a loud holosystolic murmur that reflects the left-to-right shunting across the ruptured septum. The patient usually develops acute pulmonary edema and cardiogenic shock from the left-to-right shunt.83

B. Indications for surgery. Surgery is indicated on an emergency basis for nearly all postinfarction VSDs to prevent the development of progressive multisystem organ failure. The overall surgical mortality rate is about 30%, but once the patient develops cardiogenic shock (which is often present), the surgical mortality rate is even higher.84,85 Occasionally, a small VSD with a shunt of <2:1 can be managed medically, but it usually should be repaired after 6 weeks to prevent future hemodynamic problems.

C. Preoperative considerations

1. Prompt diagnosis can be made using a Swan-Ganz catheter, which detects a step-up of oxygen saturation in the right ventricle. Two-dimensional echocardiography can confirm the diagnosis of a VSD and differentiate it from acute MR, which can produce a similar clinical scenario.

2. Inotropic support and reduction of afterload, usually with an IABP, are indicated in all patients with VSDs in anticipation of emergent cardiac catheterization and surgery.

3. Cardiac catheterization with coronary angiography should be performed to confirm the severity of the shunt and to identify associated coronary artery disease.