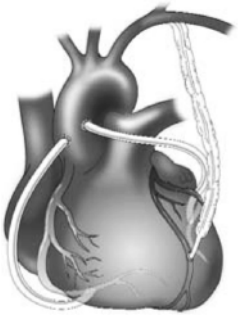

CHAPTER 1

Synopsis of Adult Cardiac Surgical Disease

1 Synopsis of Adult Cardiac Surgical Disease

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 the progressive blockage of the coronary arteries by atherothrombotic disease. Significant risk factors include hypertension, dyslipidemia (especially high LDL, low HDL, elevated Lp(a) or apoB, or triglycerides), diabetes mellitus, obesity (a combination of the above being termed metabolic syndrome), cigarette smoking, and a family history of premature CAD. 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, commonly referred to as "stable ischemic heart disease (SIHD). Plaque rupture with superimposed thrombosis is responsible for most acute coronary syndromes (ACS), which include classic "unstable angina", non-ST-elevation myocardial infarctions (non-STEMI), and ST-elevation infarctions (STEMI). Paradoxically, plaque rupture more 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.

B. Primary prevention of cardiovascular disease entails control of modifiable risk factors. Notably, statins are generally not recommended for patients with normal cholesterol levels (unless there is a family history of premature CAD) or for patients at low risk for atherosclerotic cardiovascular disease (ASCVD) based on the ASCVD risk calculator (available at https://clincalc.com/cardiology/ascvd/pooledcohort.aspx).

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Furthermore, aspirin, which had been widely utilized for primary prevention in the past, has received only a level IIb recommendation for patients age 40–70 with higher ASCVD risk, but not at increased bleeding risk, and was considered contraindicated on a routine basis in patients >age 70 or in any patient with an increased risk of bleeding according to a 2019 ACC report.[1]

C. Management strategies in stable ischemic heart disease (SIHD)

1. Symptomatic coronary disease is initially treated with medical therapy, including aspirin, nitrates, ß-adrenergic blockers, and calcium-channel blockers (CCBs). Ranolazine may be added as a second-line drug for symptomatic relief in patients with refractory angina. It inhibits inward sodium currents in the heart muscle, leading to a reduction in intracellular calcium levels, which reduces myocardial wall tension and oxygen requirements. It does not cause bradycardia and hypotension, which occasionally are limiting factors with the use of other antianginal drugs. Statins should be given to control dyslipidemias and are effective for plaque stabilization. Angiotensin-converting enzyme (ACE) inhibitors or angiotensin receptor blockers (ARBs) are given to patients with depressed left ventricular (LV) function (ejection fraction [EF] <40%) and to those with hypertension and diabetes. P2Y12 inhibitors (clopidogrel, ticagrelor) generally do not provide benefit to patients with SIHD.
2. Optimal medical therapy should be the initial management strategy for patients with SIHD, since studies have not shown that proceeding to percutaneous coronary intervention (PCI) reduces the risk of death, infarction or other major adverse cardiovascular events.[2] Thus, the decision to proceed with cardiac catheterization should be based on the rationale that the patient's symptoms are disabling enough or the degree of ischemia is significant enough to warrant an intervention to revascularize the heart. Risk stratification with noninvasive functional testing is important to provide objective evidence of inducible ischemia, using exercise stress testing, nuclear imaging, or dobutamine stress echocardiography.
3. The decision to proceed with an intervention must then take into consideration an angiographic assessment of the extent of coronary disease and an invasive assessment of its physiologic significance by fractional flow reserve (FFR)[3] or instantaneous flow reserve (iFR)[4], which is not dependent on the administration of adenosine. Additional critical information when considering PCI or coronary artery bypass grafting (CABG) includes the patient's comorbidities, particularly diabetes mellitus, and an assessment of LV function. Multiple studies comparing medical therapy with PCI for patients with SIHD have shown that PCI reduces the incidence of angina, may increase the short-term risk of myocardial infarction (MI), but does not lower the long-term risk of MI or improve survival.[5] However, PCI does reduce the need for urgent revascularization and may reduce the risk of MI in patients with a large ischemic burden. Superior clinical outcomes are achieved with complete revascularization, which in many patients is better accomplished with CABG than PCI.[6] Use of systematic anatomic assessments, such as with the SYNTAX score (see section C.4.a), has been accepted as an adjunct to this decision-making process.
4. Appropriate use criteria (AUC) with complex matrices have been set forth for coronary revascularization strategies in patients with SIHD.[7] These are subdivided by the number of diseased vessels (1–2–3), the presence of symptoms, the use of

antianginal therapy, and whether noninvasive testing indicates the patient is at low, intermediate, or high risk for a cardiac event, or in the absence of testing, by the results of FFR/iFr studies.

a. The SYNTAX score (http://www.syntaxscore.com) is also incorporated into the AUC guidelines and can be used to determine whether PCI or CABG is preferable for multivessel or left main (LM) disease. This provides an angiographic assessment of coronary disease with an additive score that evaluates the location and degree of stenosis in each vessel, the angiographic complexity of the lesion, vessel diameter and calcification. The SYNTAX trial divided patients into low risk (score of 0–22), intermediate risk (score of 23–32), and high risk (score >32) categories and used a primary end point of major adverse cardiac and cerebrovascular events (MACCE), which includes mortality, myocardial infarction (MI), stroke, and the need for repeat revascularization.

b. Five-year follow-up data from the SYNTAX trial showed that patients in the low-risk category had similar MACCE rates with PCI or CABG. However, CABG produced superior results in intermediate- to high-risk patients with three-vessel disease (score >22), and those at high risk with LM disease. In these cohorts, CABG was associated with less MACCE, more complete revascularization, reduced need for repeat revascularization, and improved long-term benefit.[8,9]

c. The FREEDOM trial showed that CABG is superior to PCI in diabetic patients with multivessel disease,[10,11] and the presence or absence of diabetes is specifically incorporated into the AUC guidelines for multivessel and LM disease. In these diabetic patients, the SYNTAX score was found to be a predictor of MACCE only with PCI, and therefore was not recommended to guide therapy.[12]

d. A "residual SYNTAX" score >8 after PCI for patients in the moderate- to high-risk cohorts, indicative of incomplete revascularization, had worse 30-day and one-year survival.[13] In fact, in the entire SYNTAX study, PCI resulted in a 10-fold increase in MI-related death compared with CABG, but this was mostly accounted for in patients with diabetes, multivessel disease, and high SYNTAX scores.[14]

e. One shortcoming of the SYNTAX score was that it correlated only an angiographic assessment with the best revascularization strategy. Because surgery might provide more benefit to patients with significant clinical comorbidities in addition to the anatomical complexity of disease, the SYNTAX II scoring system was devised. This included eight predictors – two anatomic (SYNTAX score and unprotected LM disease), and six clinical predictors (age, creatinine clearance, ejection fraction, female gender, peripheral vascular disease, and chronic obstructive pulmonary disease [COPD]). The SYNTAX II study used second-generation drug-eluting stents and intravascular ultrasound imaging with PCI. It showed that some patients with low SYNTAX scores had higher mortality rates with PCI and some with higher SYNTAX scores did better with PCI. Generally, the SYNTAX II score was a better predictor of four-year mortality rates than the original score.[15] To achieve similar four-year survival rates with PCI or CABG, it was found that young patients, females, and patients with reduced LVEF required lower SYNTAX scores, while older patients, those with COPD, and those with

unprotected LM disease did well with PCI despite higher anatomical SYNTAX scores. The SYNTAX II score can be accessed at www.syntaxscore.com and it calculates the comparative four-year survival rates for PCI and CABG.

f. Although diabetes was not a discriminator using SYNTAX II scoring, other studies, including a subanalysis from the FREEDOM trial of diabetic patients with multivessel disease, found CABG superior to PCI in both insulin-treated and noninsulin-treated diabetics, but results were generally worse after either procedure in insulin-treated diabetics.[16]

g. Thus, the SYNTAX or SYNTAX II score might be used as part of the decision-making process for the preferable mode of revascularization, since, along with older age, female gender, smoking, and diabetes, it appears to be a strong predictor of mortality and MACCE in patients undergoing PCI for multivessel disease and unprotected left main stenosis. These scoring systems provide an evidence-based justification for selecting CABG as the treatment of choice for many patients with more complex multivessel disease.

5. **Indications for surgery in SIHD – symptom relief.** The primary indication for surgical revascularization is to improve symptoms. PCI is applicable to many of these patients, but CABG must be considered for diabetic patients and those with high SYNTAX scores and when satisfactory PCI cannot be accomplished.[5]

   a. Class I indications

   - ≥1 significant stenoses with unacceptable angina despite guideline-directed medical therapy (GDMT)

   b. Class IIa indications

   - ≥1 significant stenoses in patients who cannot implement GDMT
   - Complex three-vessel disease (SYNTAX score >22) with/without proximal left anterior descending (LAD) artery stenosis

   c. Class IIb indications

   - Redo CABG with ≥1 significant stenoses with ischemia and unacceptable angina despite GDMT

6. **Indications for surgery in SIHD – improvement in survival.** Although symptom relief is one objective of any revascularization procedure, an additional important benefit is an improvement in long-term survival compared with medical therapy. For example, CABG for LM disease >50% or for multivessel disease with extensive ischemia and/or impaired LV function can accomplish this, but there are limited data showing that PCI can do the same. It is also likely that CABG can prolong life by preventing MI, whereas the same may not be true for PCI.[17] The following recommendations for surgery represent slight modification from the randomized controlled trials of patients with primarily chronic stable angina in the early 1980s and were incorporated into the 2011 guidelines for CABG.[5] These are the anatomic subsets for which improved survival has been noted compared with medical therapy. Thus, for these patients, surgery can be justified even in the absence of disabling symptoms. PCI is often utilized for many of these indications, although a survival benefit has not necessarily been demonstrated.

   a. Class I indications

   - Unprotected left main stenosis >50%
   - Three-vessel disease with/without proximal LAD disease

- Two-vessel disease with proximal LAD disease
- Survivors of sudden death with presumed ischemic-mediated ventricular tachycardia (VT)

b. Class IIa indications

- Two-vessel disease without proximal LAD disease with a large area of ischemic myocardium
- One-vessel disease with proximal LAD disease (with a left internal thoracic artery [LITA] graft)
- Proximal LAD or multivessel disease with EF 35–50% if viable myocardium in the region of intended revascularization

c. Class IIb indications

- One-, two- or three-vessel disease except left main with EF <35%

7. The optimal strategy in patients with severe ischemic LV dysfunction is somewhat controversial. The STICH (Surgical Treatment for Ischemic Heart Failure) trial comparing CABG with optimal medical therapy in patients with ischemic LV dysfunction found an increased 30-day mortality but better 10-year survival with CABG, the crossover occurring at two years.[18]

a. There was no correlation of survival with the presence or absence of angina in the intention-to-treat analysis, but there was a prognostic benefit when crossovers were included. Either way, angina relief was superior with surgery.[19]

b. Worse outcomes with medical management were noted with more extensive CAD, more LV dysfunction (EF <27%) and larger ventricles (LV end-systolic volume index >79 mL/m^2), but these risk factors were not predictive of CABG mortality – thus a greater benefit with CABG was noted in these patients.

c. Another interesting finding of the STICH trial was that there is no difference in surgical outcomes whether viability was present or not, and in fact, this observation was irrespective of treatment strategy.[20] This seemed to contradict multiple studies and meta-analyses that have shown that viability testing is helpful in assessing which patients may benefit from surgery.[21] One potential limitation of this trial was the use of thallium stress imaging, which is not as discriminatory as PET (positron emission tomography) scanning in differentiating viable from nonviable myocardium. It was concluded that viability was predictive of a survival benefit in patients with moderate LV dysfunction, but lost its prognostic benefit when LV dysfunction became severe.[19]

d. Other studies comparing PCI with CABG in diabetic patients with LV dysfunction have confirmed that CABG is associated with a lower risk of death, MI, MACE, and repeat revascularization.[22]

D. Management strategies in acute coronary syndromes

1. **Non-STEMI** patients or those with unstable angina without a troponin leak usually have the substrate for recurrent ischemia and infarction. They should be treated with aspirin (162–325 mg) and unfractionated or low-molecular-weight heparin (LMWH), as well as standard therapies (e.g. nitrates, β-blockers, statins, ACE inhibitors).[23,24] A P2Y12 inhibitor, usually clopidogrel or ticagrelor, should be given in addition to aspirin to patients with non-STEMIs, but it is not necessarily indicated in patients with normal troponin levels. Initiation of dual antiplatelet therapy will provide a clinical benefit and will also provide adequate platelet inhibition for a

PCI which is feasible in most patients to relieve ischemia and prevent infarction. In patients who are considered intermediate–high risk for a clinical event or exhibit a large thrombus burden, the addition of a glycoprotein (GP) IIb/IIIa inhibitor may be considered (class IIb indication). If PCI is not feasible or is unsuccessful, a CABG is indicated for the anatomic findings listed in section C.6.

a. Low-risk patients may stabilize on medical therapy and can undergo risk stratification by noninvasive testing to assess the extent of inducible ischemia (the "ischemia-guided strategy"). Various scoring systems (GRACE or TIMI score for UA/NSTEMI) can be used to quantitate the patient's short-term risk of an ischemic event. The GRACE score provides estimates of in-hospital and six-month mortality and the TIMI score provides the 14-day risk of mortality, new or recurrent MI, or severe recurrent ischemia requiring urgent revascularization. Both of these scoring systems are available at a variety of sites on-line, including www.mdcal.com (search "GRACE" or "TIMI").[24]

b. In patients at intermediate–high risk, an "early invasive strategy" is used, which triages the patient to early catheterization. Although this strategy is considered to lead to improved outcomes compared with the ischemia-guided approach, some studies show that 10-year outcomes are comparable.[25] This approach provides an early definition of the patient's coronary anatomy and allows for early intervention to prevent myocardial damage. This strategy has been subdivided into immediate (<2 hours), early (<24 hours), or delayed (25–72 hours) catheterizations, depending on the patient's presentation. The immediate approach is applicable to patients with recurrent or refractory angina, ECG changes at rest, new-onset heart failure (HF), new-onset mitral regurgitation (MR), or hemodynamic instability. New ST depressions with rising troponins or a GRACE score >140 are an indication for an early approach, and patients with diabetes, chronic kidney disease, EF <40%, a GRACE score of 109–140, or a TIMI score ≥2 can have a delayed invasive approach.[24,26]

c. Since most patients are given a P2Y12 inhibitor upon hospital admission, when the extent of their coronary disease is not known, there will be patients undergoing catheterization in whom PCI is not feasible or in whom the benefits of CABG outweigh those of PCI (i.e. most diabetic patients with multivessel disease and patients with distal LM disease). An urgent CABG may then be recommended. A lower risk of renal dysfunction is noted for patients having on-pump CABG if surgery can be delayed for 24 hours after catheterization.[27] However, the timing of surgery must primarily balance the risk of a recurrent ischemic event vs. the risk of excessive bleeding. For patients requiring urgent, but not emergent, surgery who receive a P2Y12 inhibitor, surgery should be delayed at least 24 hours, if possible, and platelet aggregation testing obtained to elucidate whether the patient is sensitive or not to the P2Y12 inhibitor.[28,29] If inhibition is <30%, surgery can usually be done safely without resorting to platelet transfusions to control mediastinal bleeding.

2. **ST elevation infarctions (STEMIs)** are usually associated with coronary occlusions, and are preferentially treated by primary PCI, 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 a "door to balloon" time of less than 90 minutes. However, PCI should still be considered up to 12 hours after the onset of symptoms, at 12–24 hours

if the patient has HF, persistent ischemic symptoms, or hemodynamic or electrical instability, or at any time if cardiogenic shock is present.[24] For the latter, emerging data suggest that improved survival may be achieved using mechanical circulatory support (MCS), such as an Impella (Abiomed, Danvers, MA) device, prior to PCI.[30,31] All patients presenting with a STEMI and with no contraindications to antiplatelet treatment should be given one dose of aspirin 325 mg, a load of either clopidogrel 600 mg or ticagrelor 180 mg, and either unfractionated heparin or bivalirudin upon presentation to the emergency room, if not sooner (i.e. in the ambulance).

a. If PCI of the culprit vessel can be accomplished in a patient with multivessel disease, it remains controversial as to whether stenting of other nonculprit stenotic vessels should be performed at the same time, even in patients with cardiogenic shock, although some observational studies do suggest a benefit.[32,33] However, if it is concluded that the other vessels would be better revascularized by surgery, the patient may be referred for CABG having received a P2Y12 inhibitor to prevent stent thrombosis. Once the culprit vessel has been opened, surgery is rarely required emergently. Thus, the oral P2Y12 inhibitor may be stopped and the patient given either a short-acting P2Y12 inhibitor (IV cangrelor) or a GP IIb/IIIa inhibitor as a bridge to surgery.

b. If PCI cannot be accomplished or is considered inadvisable due to extensive LM or multivessel disease, emergency surgery should be performed. Early surgical studies showed little myocardial salvage if CABG was not performed within six hours, with a significant increase in mortality for surgery performed between 7 and 24 hours, and then a lower mortality thereafter.[34] Thus, beyond six hours, surgery may be delayed in the absence of cardiogenic shock, active ischemia, or a significant area of myocardium at risk, although the latter is usually present. However, active ischemia with or without cardiogenic shock should usually be treated urgently by CABG, independent of the time since presentation. In a report from the STS database, the operative mortality rate for patients in cardiogenic shock was about 20%, but it was 37% in patients requiring intraoperative MCS and 58% in patients requiring postoperative MCS support.[35] Thus, if cardiogenic shock is present without active ischemia or with end-organ dysfunction, consideration might be given to use of MCS alone.[24]

c. If PCI cannot be performed or has failed, the ACC guidelines recommend emergency surgery for the following:

i. Class I

- Persistent ischemia or hemodynamic instability refractory to nonsurgical therapy (it is not stated if that includes an intra-aortic balloon pump [IABP])
- Cardiogenic shock irrespective of the time from MI to the onset of shock and the time from MI to CABG
- Mechanical complications of MI
- Life-threatening ventricular arrhythmias with LM or three-vessel disease

ii. Class IIb

- Multivessel disease with recurrent angina or MI within 48 hours of presentation
- Patients >age 75 with ST elevation or left bundle branch block (LBBB) regardless of time since presentation if in cardiogenic shock

E. CABG vs. PCI as a revascularization strategy – other comments

1. The ongoing debate about the relative merits and advantages of CABG or PCI has spawned innumerable studies, publications, and controversies. PCI is generally utilized for patients with a lesser extent of disease, as noted in the appropriate use criteria (AUC) guidelines, and should incorporate SYNTAX scores in the decision. However, PCI is also useful in patients at very high risk for surgery due to either very advanced "nonbypassable" coronary disease or significant comorbidities that make surgery a prohibitive risk. Mechanical circulatory-supported PCI procedures, primarily using the Impella devices have been performed successfully in high-risk cases.[36]
2. Studies have shown that FFR-guided, rather than anatomy-guided, PCI produces superior outcomes in patients with SIHD, reducing the need for urgent revascularization.[37] In the 2011 ACC guidelines for CABG, there is no mention of using an FFR-guided approach to surgical revascularization. Some studies have shown that this approach results in less grafting, a higher graft patency rate, a lower rate of angina, and a significant reduction in MI and mortality out to six years.[38–40] Such information could be helpful in deciding which patients should undergo surgery and in fact which vessels need to be bypassed.
3. Second-generation drug-eluting stents (DES) have been associated with a lower risk of restenosis requiring repeat revascularization, lower rates of stent thrombosis, and fewer MIs than bare-metal stents (BMS), without a significant impact on mortality.[41] Although the risk of stent thrombosis may be greater in patients who are resistant to the antiplatelet effects of aspirin and/or a P2Y12 inhibitor, platelet function testing has not been that useful in adjusting treatment and influencing outcomes.[42] To minimize the risk of stent thrombosis, it is recommended that patients receiving a BMS take aspirin and a P2Y12 inhibitor for at least one month, and those receiving a DES take these medications for at least six months to one year.[43]
4. One should not consider either PCI or CABG an exclusive approach to a patient's CAD. For example, one hybrid approach is to perform a PCI of the culprit lesion causing a STEMI to achieve prompt myocardial salvage and then refer the patient for surgical revascularization of other lesions. If a patient does undergo PCI and urgent surgery is then recommended, a strategy must be devised to minimize the risk of stent thrombosis while minimizing the risk of perioperative bleeding. It has even been proposed that placing a LITA to the 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.[44,45] However, one study did suggest that the rate of mid-term reinterventions rates was higher using a hybrid approach.[46]

F. Preoperative considerations

1. A thorough history and physical examination is imperative when cardiac surgery is being contemplated. Whereas PCI specifically addresses the patient's cardiac issues with minimal impact on other organ systems except the kidneys, open-heart surgery can produce a significant number of potential morbidities, especially in patients with pre-existing problems, such as COPD, hepatic or renal dysfunction, cerebrovascular disease, diabetes, etc. Careful attention to and management of such issues prior to surgery may optimize surgical outcomes. These issues are discussed in detail in Chapter 3.

2. **Myocardial 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, anti-ischemic medications to control heart rate and blood pressure (IV nitrates and β-blockers), antiplatelet and anticoagulant medications (aspirin, P2Y12 inhibitors, heparin, GP IIb/IIIa inhibitors), and/or placement of an 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 elective cardiac surgery patients, although this is probably limited to patients sustaining a remote infarction.[47,48] 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 an ACS, left main coronary disease, or a preoperative IABP. The heparin may be stopped about four hours prior to surgery, but in patients at higher risk for ischemia, it may be continued up to the time of surgery without causing problems with central line insertion. 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.
   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 24 hours prior to surgery to minimize the risk of perioperative bleeding. The **non-vitamin K antagonist oral anticoagulants** (NOACs) (dabigatran, apixaban, rivaroxaban, edoxaban) should be stopped 48 hours prior to surgery and probably longer in patients with renal dysfunction.[49–51] **Fondaparinux**, occasionally used for venous thromboembolism prophylaxis, has a half-life of 17–21 hours and must be stopped at least 60 hours prior to surgery.
   d. **Aspirin** is routinely used in patients with known coronary disease or is given upon presentation to the hospital. Aspirin 81 mg should be continued up to the time of surgery for virtually all patients undergoing CABG, since most studies have demonstrated improved outcomes without a significant increase in the risk of bleeding.[52–55]
   e. Preoperative use of **P2Y12 inhibitors** within a few days of surgery has been shown to significantly increase the risk of bleeding and re-exploration for bleeding. Thus, it has been recommended that clopidogrel and ticagrelor be stopped for five days and prasugrel for seven days before elective surgery.[55] Stopping the medication for only three days may be acceptable prior to off-pump surgery.[56] Platelet aggregation testing, more so than the duration of cessation prior to surgery, may dictate when surgery can be performed with a lower risk of bleeding.[28,29]
      i. In some cases, emergency balloon angioplasty and potential 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 short-acting platelet inhibitor as a bridge to surgery to minimize the risk of stent thrombosis. IV cangrelor is preferable as it has a half-life of 3–6 minutes and need be stopped only 1–2 hours before surgery.[57] Alternatively, a GP IIb/IIIa inhibitor can be used and should be stopped four hours prior to surgery so that by the time surgery starts, 80% of platelet activity will have recovered.

ii. In patients requiring surgery who have had prior stenting (<1 month for a BMS and 6–12 months for a DES), there is an increased risk of stent thrombosis if the P2Y12 inhibitor is stopped. P2Y12 reaction units (PRU) testing may indicate the patient's sensitivity to the drug. It is best to avoid operating if the PRU suggests >30% inhibition. In the absence of such testing, stopping the medication for three days may leave some residual protective antiplatelet activity, yet hopefully cause less intraoperative bleeding.

f. **Anemia** is associated with worse clinical outcomes after surgery, but this may be related to its association with other risk factors, such as HF or chronic kidney disease. In fact, it has been reported that blood transfusions have a greater impact on risk-adjusted morbidity and mortality than the anemia itself.[58–61]

i. Most hospitalized patients suffer from hospital-acquired anemia, which results from repeated blood withdrawal for lab tests as well as the blood loss and hydration during a catheterization procedure. Guidelines recommend transfusion for a hemoglobin (Hb) <8 g/dL in patients with an ACS, although hemodynamically unstable patients may benefit from a Hb level between 8 and 10 g/dL.[58,61]

ii. Even in the stable patient awaiting surgery, it is not unreasonable to give a blood transfusion prior to surgery if the anticipated hematocrit (HCT) on pump will be <20%. Low hematocrits on pump will 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 cardiopulmonary bypass (CPB). A HCT below 20% has been associated with an increased risk of renal dysfunction, stroke, ischemic optic neuropathy, and mortality. Patients with profound anemia during surgery also tend to bleed more and require more blood component transfusions. Thus, preoperative transfusion 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. Other preoperative medications to be considered include the following:

a. **Amiodarone** is beneficial in reducing the incidence of postoperative atrial fibrillation (AF). Protocols that initiate amiodarone prior or during surgery have been utilized successfully (see pages 623–624 in Chapter 11).[62]

b. **Statins** have been demonstrated to reduce operative mortality, the risks of stroke, delirium, AF, and arguably the risk of acute kidney injury.[63–66]

c. **Steroids** have been evaluated as a means of reducing the systemic inflammatory response to surgery and have been shown to improve myocardial function and possibly reduce the incidence of AF.[67] 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.

G. Surgical procedures

1. **Traditional coronary artery bypass grafting** is performed through a median sternotomy incision with use of CPB. Myocardial preservation is 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 1.1).
   - **a.** 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, but with more experience, this has not been found to be an issue.[68–70]
   - **b.** Use of additional arterial conduits (bilateral ITAs, radial artery) can be recommended to improve event-free survival.[71–73] The radial artery can be harvested endoscopically using a tourniquet to minimize bleeding during the harvest with placement of a drain afterward to prevent blood accumulation within the tract. With radial artery grafting, use of a topical vasodilator, such as a combination of verapamil-nitroglycerin, is useful in minimizing spasm.[74] The STS guidelines suggest use of a systemic vasodilator during surgery, and IV diltiazem 0.1 mg/kg/h

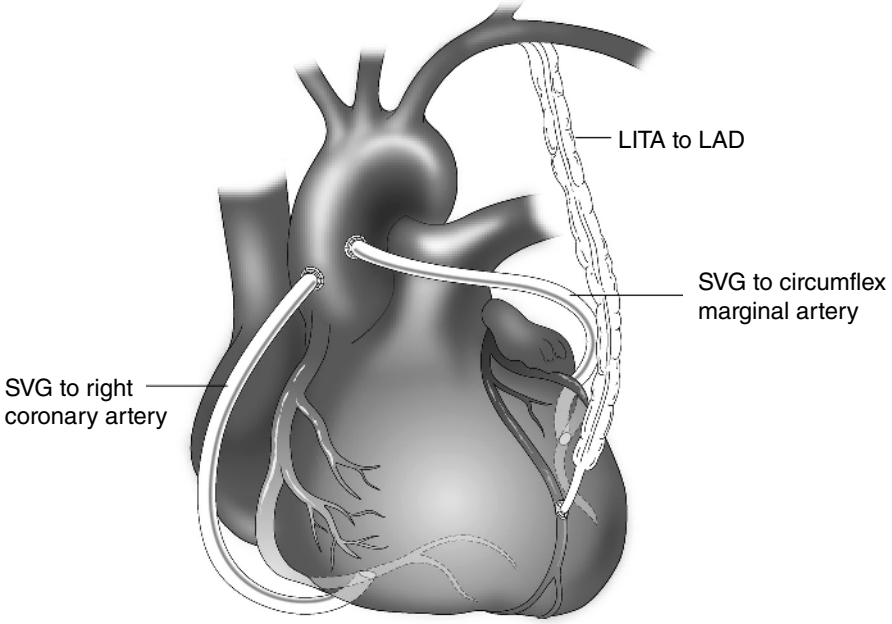


Figure 1.1 • Coronary artery bypass grafting. A left internal thoracic artery (LITA) has been placed to the left anterior descending (LAD) artery with aortocoronary saphenous vein grafts (SVG) to the circumflex marginal and right coronary arteries.

(usually 5–10 mg/h) or IV nitroglycerin 10–20 μg/min (0.1–0.2 μg/kg/min) are commonly used.[71] This is continued in the intensive care unit and then converted to either amlodipine 5 mg po qd or Imdur 20 mg po qd for several months. The purported benefit of such pharmacologic management to prevent spasm has been universally accepted, although not rigorously studied, and routine use may not be indicated.[75]

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 1.2). Intracoronary or aortocoronary shunting can minimize ischemia after an arteriotomy is performed.
   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.

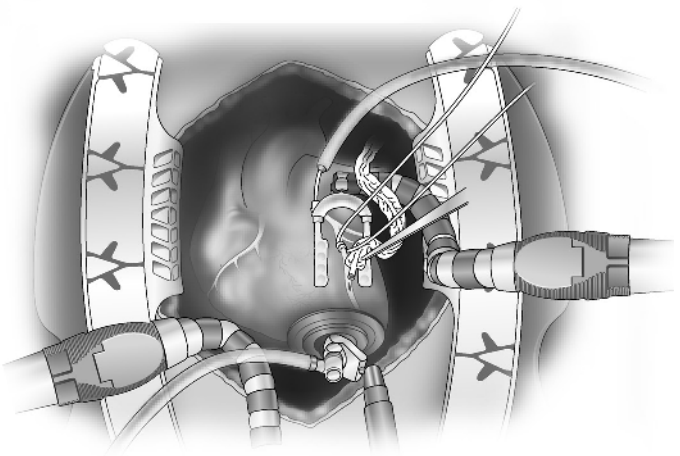


Figure 1.2 • Off-pump bypass grafting requires displacement of the heart using techniques to avoid hemodynamic compromise. These may include placement and elevation of deep pericardial sutures or the use of an apical suction device. A stabilizing device is used to minimize motion and a proximal vessel loop is placed to minimize bleeding at the site of the anastomosis.

b. OPCABs reduce transfusion requirements and the incidence of AF, but whether there is a reduction in the risk of stroke and renal dysfunction remains controversial.[76] OPCABs generally result in fewer grafts being placed, resulting in more incomplete revascularization and more repeat revascularization. Numerous long-term follow-up studies have shown inferior survival to on-pump surgery.[77–79] Enthusiasm for this technique is modest, and it is estimated that less than 20% of CABGs are performed off-pump. One randomized trial did show better outcomes with OPCABs when performed for a STEMI within six hours from the onset of symptoms or for patients in cardiogenic shock,[80] but most 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 (RV) 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 an aortic punch, 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. Bilateral ITAs can be harvested under direct vision and an additional incision is made in the right chest to bypass the right coronary artery.[81,82] Combining an LITA to the LAD with stenting of other vessels ("hybrid" procedure) has also been described. A meta-analysis of the MIDCAB procedure found a lower risk of repeat revascularization compared with PCI of the LAD.[83]
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.[84] 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. Anesthetic concerns during this procedure are discussed in Chapter 4, pages 265–266.
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 is most commonly used as adjunct to CABG in viable regions of the heart where bypass grafts cannot be placed.[85,86] It can also be used as a sole procedure performed through a left thoracotomy or thoracoscopically for patients with inoperable CAD in regions of viable myocardium.[87] TMR has a level IIb indication to improve symptoms and may be reasonable to consider in patients with viable ischemic myocardium in areas that cannot be grafted.[5]

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. Most LVAs occur in the anteroapical region due to occlusion of the LAD without collateralization, and are more likely to form in the absence of a patent infarct-related vessel. In contrast, early reperfusion of an occluded vessel by PCI or thrombolytic therapy 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 an LVA associated with an ischemic cardiomyopathy is heart failure (HF) due to systolic dysfunction. With LVAs, there is a reduction of forward stroke volume caused by geometric remodeling of the aneurysmal segment due to loss of contractile tissue and an increase in ventricular dimensions. This results in an increase in wall stiffness and an increase in the LV end-diastolic pressures. 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, with thrombus being noted in over 50% of cases. Malignant ventricular arrhythmias or sudden death may result from either enhanced automaticity or triggered activity related to myocardial ischemia and increased myocardial stretch, or to 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 or mildly symptomatic patient with significant volume overload causing LV dilatation and reduced ventricular function prior to the development of advanced HF symptoms. It may also be considered where there is extensive clot formation present within the aneurysm. However, surgery is most commonly indicated to improve symptoms and prolong survival when one of the four clinical syndromes (angina, HF, embolization, or arrhythmias) is present. Arrhythmias may be treated by a nonguided endocardial resection through the aneurysm with/without cryosurgery along with subsequent placement of a transvenous implantable cardioverter-defibrillator (ICD).

D. Preoperative considerations

1. 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. Biplane left ventriculography is helpful in identifying regions of akinesia and dyskinesia and assessing the function of noninfarcted segments. Cardiac CT angiography or cardiovascular magnetic resonance imaging (CT-MRI) are also helpful in making the diagnosis, and the latter can also be used to assess myocardial viability.[88]
2. Patients with LVAs with LV dysfunction are usually managed with an ACE inhibitor and ß-blocker. Anticoagulation may also be given during the early postinfarction period, but may not be necessary in chronic aneurysms with thrombus due to the low risk of embolism.[89] If the patient remains on warfarin, bridging to surgery with heparin can be recommended.

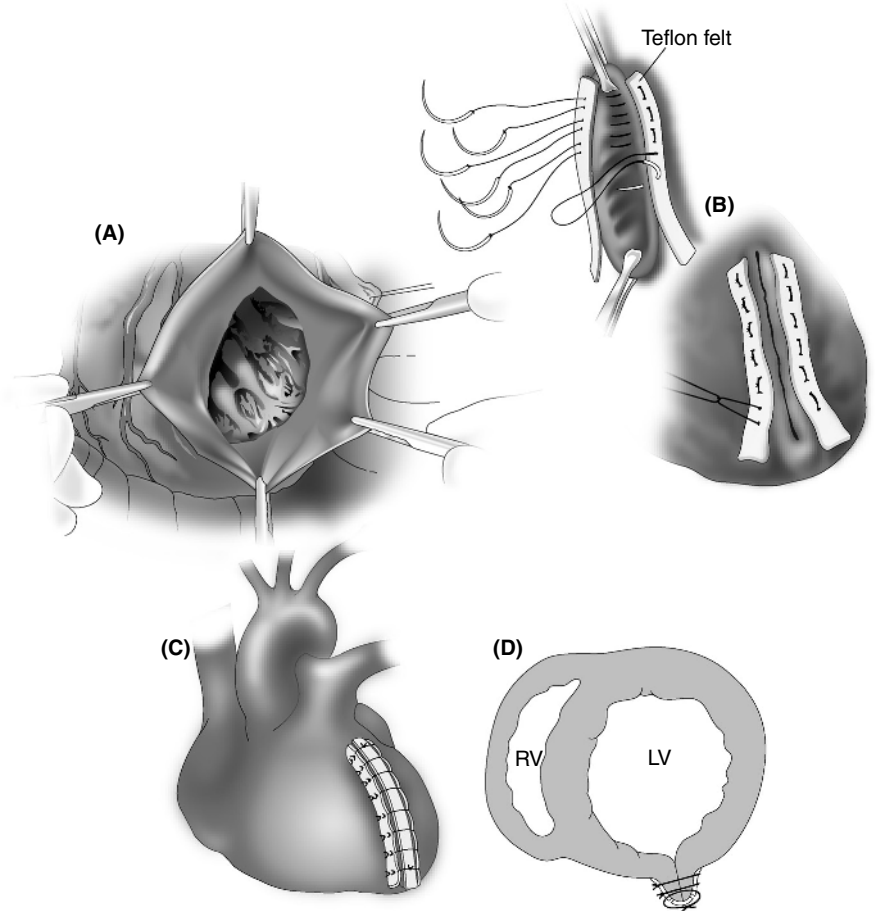


Figure 1.3 • Repair of a left ventricular aneurysm (LVA) using the linear closure technique. (A) The thinned-out scar tissue is opened and partially resected. Any LV thrombus is removed. (B) The aneurysm is then closed with mattress sutures over felt strips. (C) An additional over-and-over suture is placed over a third felt strip. (D) Cross-section of the final repair.

E. Surgical procedures

1. Standard aneurysmectomy ("linear repair") 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 1.3).[90,91]
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 "endoaneurysmorrhaphy" 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

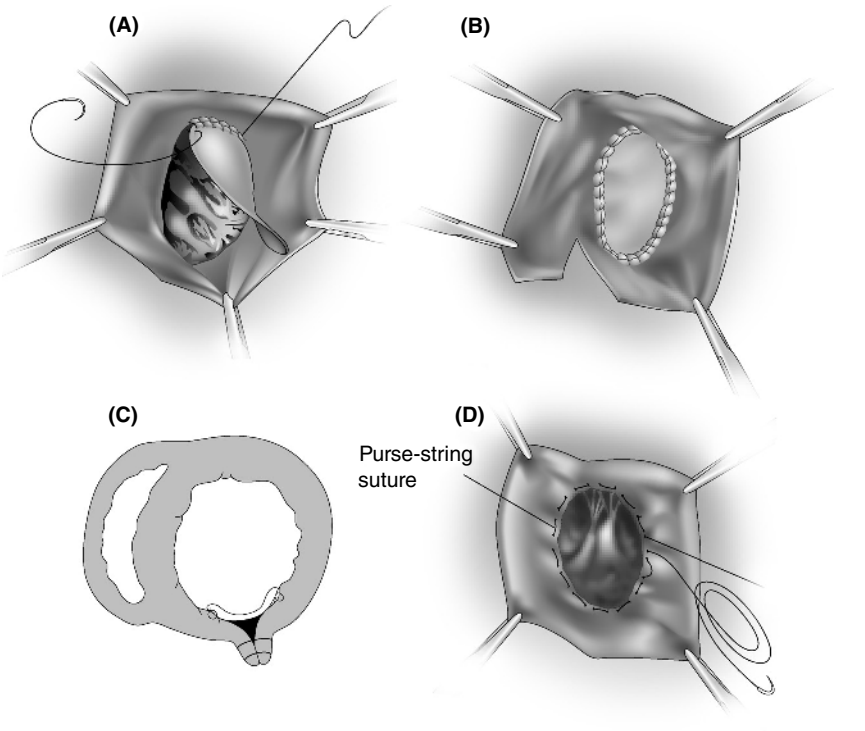


Figure 1.4 • Repair of a LVA using the endoaneurysmorrhaphy technique. (A, B) A pericardial patch is sewn at the base of the defect at the junction of the scar and normal myocardium to better preserve ventricular geometry. The resected edges of the LV are closed in a similar fashion to the linear technique. (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.

(Figure 1.4). This preserves LV geometry and improves ventricular function to a greater degree than the line ar 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 LVAs as well as cases of ischemic cardiomyopathy with anterior akinesis (Figure 1.4D).[92,93] The procedure involves placement of an encircling suture at the junction of the contracting and noncontracting segments, and then 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.[94–96] However, the

STICH trial of patients with CAD-related anterior akinesia or dyskinesia with an EF <35% was unable to demonstrate that reduction in LV size was associated with an improvement in symptoms or a reduction in mortality after four years.[97]

3. For patients with recurrent ventricular tachycardia, an endocardial resection with or without endocardial mapping may be performed with good results.[98,99]
4. 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.
5. A mitral valve procedure is also indicated if the severity of 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. Mitral valve repair with a complete annuloplasty ring may be successful when performed with ventricular restoration.

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 anteroapical region (from occlusion of the LAD artery), and less commonly in the inferior wall (usually from occlusion of the right coronary artery). It is noted in less than 1% of acute MIs, and the incidence has declined because of early reperfusion therapy for STEMIs. 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.[100]

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. A report from the STS database in 2012 noted an operative mortality rate of 54% if surgery was performed within seven days of an infarction, usually because the patient was hemodynamically unstable and often in cardiogenic shock. For surgery performed after seven days, the mortality rate decreased to 18.4%, most likely because these patients were more hemodynamically stable, had smaller VSDs and <2:1 shunts, and were naturally selected to have survived long enough to survive subsequent lower-risk surgery.[101] Risk factors for operative mortality included preoperative dialysis, older age, female gender, cardiogenic shock, use of an IABP, moderate–severe MR, redo operation, and emergency status.[102]

C. Preoperative considerations

1. Prompt diagnosis can be made using a Swan-Ganz catheter, which detects a step-up of oxygen saturation in the RV. Two-dimensional (2D) 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 virtually 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 CAD.

D. Surgical procedures

1. The traditional surgical treatment for postinfarct VSDs had been the performance of a ventriculotomy through the infarcted zone, resection of the area of septal necrosis, and Teflon felt or pericardial patching of the septum and free wall. This technique required transmural suturing and was prone to recurrence.
2. The preferred approach is to perform circumferential pericardial patching around the border of the infarcted ventricular muscle. This technique excludes the infarcted septum to eliminate the shunt and reduces recurrence rates, because suturing is performed to viable myocardium away from the area of necrosis (Figure 1.5).[103]
3. Coronary bypass grafting of critically diseased vessels should be performed. Early studies suggested this improved short- and long-term survival after surgery, but more recent data from the STS database did not corroborate this.[101,104]

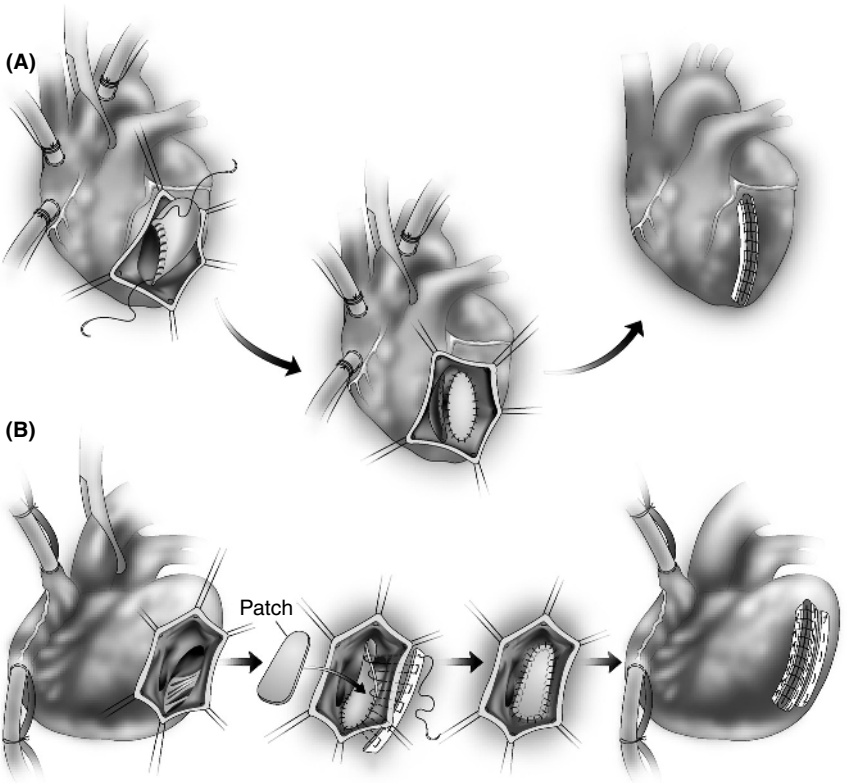


Figure 1.5 • Closure of a postinfarction ventricular septal defect (VSD) using the exclusion technique. (A) Anterior VSD. (B) Inferior VSD. The pericardial patch is anchored to viable myocardium away from the site of the defect, thus eliminating shunt flow across the septal defect. (Reproduced with permission from David et al., *Semin Thorac Cardiovasc Surg* 1998;10:105–10.)[103]

4. Consideration may be given to percutaneous VSD closure with the Amplatzer VSD closure device in patients with smaller VSDs or prohibitive surgical risks.[105] Use of MCS may also be considered in patients in cardiogenic shock to improve hemodynamics and organ system function, allowing for a lower-risk nonemergency procedure at a future date.

IV. Aortic Stenosis

A. Pathophysiology. Aortic stenosis (AS) results from thickening, calcification, and/or fusion of the aortic valve leaflets, which produce an obstruction to LV outflow.[106,107] In younger patients, AS usually develops on congenitally bicuspid valves, whereas in older patients, degenerative change in trileaflet valves is more common. Aortic sclerosis is a very common finding in elderly patients, and may be a manifestation of atherosclerosis, but usually does not progress to AS. Progression of AS may be related to endothelial cell activation and atherogenesis, as it is associated with the presence of cardiac risk factors, including hypertension, hyperlipidemia, and diabetes, but it has not been shown that statins or other medical therapy will slow the progression of degenerative AS.[108,109]

1. The impairment to cusp opening leads to pressure overload, compensatory left ventricular hypertrophy (LVH), and reduced ventricular compliance. The development of LVH maintains normal wall stress and a normal EF.
2. If the increase in wall thickness does not increase in proportion to the rise in intraventricular pressure, wall stress will increase and EF will fall. It is important to assess whether a reduced EF in patients with severe AS is the result of excessive afterload (i.e. inadequate hypertrophy to overcome the obstruction) or depressed contractility. If the latter is present, surgical risk is higher.
3. In patients with excessive and inappropriate degrees of LVH, wall stress is low and the heart will become hyperdynamic with a very high EF. This finding portends a worse prognosis after surgical correction.[110]

B. Symptoms. The classic symptoms associated with AS are angina, shortness of breath, and syncope. However, fatigue with limited activity appears to be one of the first symptoms described by most patients.

1. Angina may result from the increased myocardial oxygen demand caused by increased wall stress, from reduction in blood supply per gram of hypertrophied tissue, and/or from limited coronary vasodilator reserve. Hypertrophied hearts are more sensitive to ischemic injury, and exercise may induce subendocardial ischemia, inducing systolic or diastolic dysfunction. Thus, angina may occur with or without concomitant epicardial CAD.
2. Congestive HF results from elevation of filling pressures (LV end-diastolic pressure) with diastolic dysfunction and eventually by progressive decline in LV systolic function. This results in progressively worsening dyspnea on exertion.
3. Cardiac output is relatively fixed across the valve orifice and can lead to faintness, dizziness, or frank syncope in the face of peripheral vasodilation.
4. Palpitations may occur with the occurrence of AF, which, if persistent, leads to clinical deterioration, because the hypertrophied ventricle relies on atrial contraction to maintain a satisfactory stroke volume.

C. Diagnosis. Most patients do not become symptomatic until the degree of AS becomes severe (Table 1.1). The severity of AS is preferentially assessed by Doppler

Table 1.1 • Stages of Aortic Stenosis

Stage A: At risk for AS
Stage B: Progressive AS
Stage C: Asymptomatic severe AS (with AVA <1 cm^2)
C1: Asymptomatic with mean gradient >40 mm Hg
C2: Asymptomatic with LV dysfunction
Stage D: Symptomatic severe AS (with AVA <1 cm^2)
D1: Symptomatic with high-gradient AS
D2: Symptomatic with severe low flow/low gradient AS with reduced LVEF
D3: Symptomatic with severe low flow/low gradient AS with normal LVEF (paradoxical low flow)[106]

Table 1.2 • Echocardiographic Assessment of the Severity of Aortic Stenosis

Indicator	Mild	Moderate	Severe
Jet velocity (m/s)	<3.0	3.0–4.0	>4.0
Mean gradient (mm Hg)	<25	25–40	>40
Aortic valve area (cm^2)	>1.5	1.0–1.5	<1.0
Aortic valve area index (cm^2/m^2)			<0.6
Dimensionless index			<0.25

echocardiography, with evaluation by cardiac catheterization only indicated in equivocal cases. Performing a left heart catheterization and crossing the valve to measure gradients in a patient with known severe AS is considered a contraindication by the ACC guidelines (Level III indication) because of the increased risk of embolic stroke.[111] Coronary angiography is indicated before surgery to identify whether CAD is present.

1. Doppler echocardiography assesses the severity of AS by measuring the maximum instantaneous jet velocity and the mean transvalvular gradient, and allows for calculation of the aortic valve area (AVA) using the continuity equation (Tables 1.2 and 1.3, Figure 1.6). Because this calculation also includes the cross-sectional area of the left ventricular outflow tract (LVOT), it may indicate a very small valve area in a very small patient when severe stenosis may not be present. Using the ratio of the velocity time integral (VTI) of the LVOT to the aorta to eliminate the LVOT measurement provides a "dimensionless index". Echo imaging in the short-axis view can also measure the valve area directly by planimetry and can give an appreciation of the degree of calcification and cusp separation during systole.

Table 1.3 • Hemodynamics of Advanced Stages of Aortic Stenosis with Indications for AVR

Stage	Symptoms	AVA	Peak velocity (m/s)	Mean gradient (mm Hg)	Other considerations
C1	No	<1 cm^2	>4	>40	Severe leaflet calcification or positive ETT
C2	No	<1 cm^2	>4	>40	LV dysfunction (EF <50%)
D1	Yes	<1 cm^2	>4	>40	
D2	Yes	<1 cm^2	<4	<40	LV dysfunction (EF <50%)
D3	Yes	<1 cm^2	<4	<40	SVI <35 mL/m^2

SVI, stroke volume index

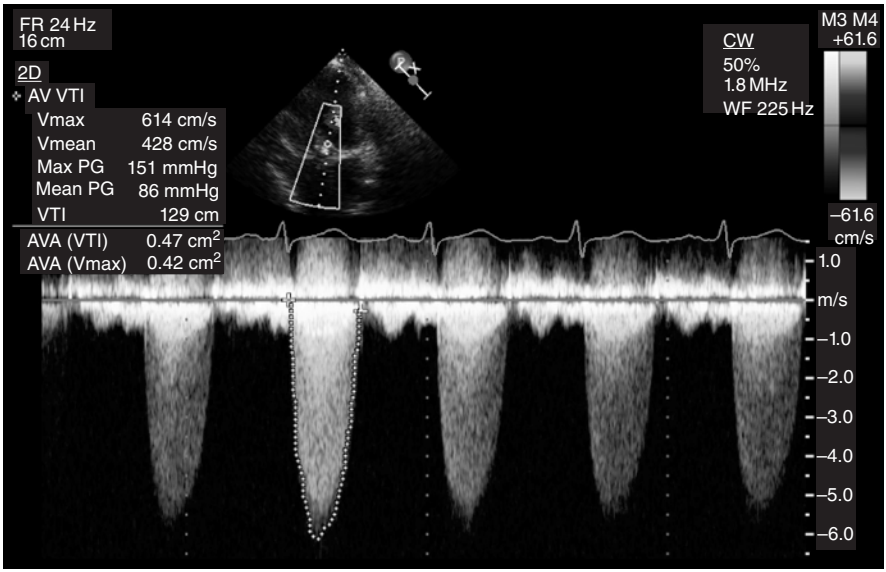


Figure 1.6 • Two-dimensional echocardiogram with continuous wave Doppler demonstrating very severe aortic stenosis.

2. Since the pressure gradient is related to both the orifice area and the transvalvular flow, low gradients may be noted with low stroke volumes despite an AVA of <1 cm^2. This issue of AVA-gradient discordance might create confusion as to which patients actually have severe AS and would benefit from an intervention versus those who might not.[112–114] Therefore, a critical measurement during echocardiography is calculation of the stroke volume index (SVI). A low-flow state (SVI

<35 mL/m^2) can be seen in patients with reduced or preserved EF. This concept has led to a classification system incorporating SVI and EF.[115]

a. **Normal-flow, high gradient** (NF/HG), which fits the classic definition of severe AS (i.e. AVA <1 cm^2, peak velocity (Vmax) >4 m/s, or a mean gradient >40 mm Hg).
b. **Normal-flow, low gradient** (NF/LG), which in most cases is not severe AS. However, some studies have shown that NF/LG patients with an indexed AVA <0.6 cm^2/m^2 have improved survival with aortic valve replacement (AVR).[113,114]
c. **Low-flow, high gradient** (LF/HG), which by virtue of gradient and AVA would be severe AS.
d. **Low-flow, low-gradient** (LF/LG), which can be seen with a normal EF, termed "paradoxical LF/LG" AS (stage D3 if symptomatic) or with a reduced EF (stage D2 if symptomatic). In the LF/LG patient, survival without surgery appears to be worse than in the other groups, and survival is markedly improved by AVR.[116]

3. Dobutamine stress echocardiography (DSE) is an important test in patients with LF/LG as well as NF/LG AS to corroborate the severity of AS. In patients with normal LV function, it has limited value except to indicate that the patient might have pseudo-severe AS. However, in patients with impaired LV function, it can be used to determine contractile reserve and assess whether the patient has true or pseudo-severe AS. The latter is present if dobutamine increases cardiac output without a concomitant increase in gradient, so the AVA increases to >1 cm^2. About one-third of patients with LF/LG, both with normal and reduced EF, are felt to have pseudo-severe AS.[113]
4. Quantification of aortic valve calcium has been recommended as a means of identifying severe AS in patients with LF/LG and NF/LG and has correlated with clinical outcomes.[117–119]
5. Assessment of the degree of AS is generally not indicated at the time of catheterization, except in equivocal cases. The AVA is calculated by most cath lab software programs and is derived from a measurement of transvalvular flow (essentially the cardiac output or stroke volume) and the peak and mean pressure gradients across the valve calculated from pressures obtained on a catheter pull-back from the LV into the aorta (Figure 2.4, page 136). The AVA may be manually calculated using the Gorlin formula:

$$\text{AVA} = \frac{\text{CO}/(\text{SEP} \times \text{HR})}{44.3 \times \sqrt{\text{mean gradient}}}$$

where:

AVA = aortic valve area in cm^2 (normal = 2.5 – 3.5 cm^2)
CO = cardiac output in mL/min
SEP = systolic ejection period/beat
HR = heart rate

Alternatively, the simplified Hakki formula calculates the AVA as follows:

$$\text{AVA} = \frac{\text{CO (liters/min)}}{\sqrt{\text{peak-to-peak gradient}}}$$

6. If the above tests confirm the presence of severe AS, yet the patient is asymptomatic, exercise testing may be used to assess whether AVR may be indicated.[120,121] A meta-analysis reported that adverse cardiac events were three times more likely to occur in patients with an abnormal stress test, which was defined as the development of symptoms, a decrease in blood pressure or an increase in systolic pressure of <20%, <80% of normal exercise tolerance, ≥2 mm ST depression during exercise, or the development of complex ventricular arrhythmias. Thus, these findings were incorporated into the 2014 indications for AVR, such that a positive stress test was a level I indication for AVR.
7. Virtually all of the indications for AVR in the guidelines are for patients with severe AS, whether symptomatic or not. However, some patients with moderate AS and LV systolic dysfunction are symptomatic and at risk for adverse clinical events. It is not clear if earlier AVR may be beneficial to these patients.[122]

D. Natural history

1. It is estimated that approximately 40% of patients with asymptomatic severe AS will become symptomatic within two years and about 67% will be symptomatic by five years.[123,124] The rate of progression of AS is variable, and serial echocardiograms should be performed to assess for the rate of hemodynamic progression, which is predictive of clinical outcome. Patients with high jet velocities, LV hypertrophy, or severe valve calcification have a faster rate of progression of valve stenosis and a shorter symptom-free interval.
2. The presence of LV systolic dysfunction is an uncommon but ominous prognostic sign, as the long-term outlook is dismal. Although survival is generally improved by AVR for patients with LV dysfunction caused by afterload mismatch, a study from the Mayo Clinic reported a nearly 50% five-year mortality for asymptomatic patients with severe AS with an EF <50% with no survival benefit noted for AVR.[125] Another study of patients with moderate AS yet LV dysfunction found that most patients were symptomatic and were at high risk for clinical events.[122]
3. BNP (brain natriuretic peptide) levels in asymptomatic patients correlate with adverse events, including aortic valve-related deaths and HF admissions, so BNP or pro-BNP levels can serve as markers supporting early AVR.[126]
4. Once symptoms of AS are present, the prognosis for untreated AS is very poor with an average survival of one to two years and a less than 20% chance of surviving five years.[127] These data have been confirmed in the era of transcatheter aortic valve replacement (TAVR), with the PARTNER B cohort of "inoperable" patients having a 50% one-year mortality without AVR.[128] Patients with symptoms of heart failure (HF) have the worst survival, averaging only one year, whereas average survival is two years for patients with syncope and four years for patients with angina.
5. AVR has unequivocally been shown to improve survival, and in elderly patients has been found to restore a normal life expectancy. However, in younger patients (age <50), one study found a substantial loss in life expectancy.[129] It can be

theorized that intervention prior to the development of myocardial fibrosis might improve long-term results, thus justifying early intervention in asymptomatic patients with severe aortic stenosis.[130]

E. Indications for AVR per 2014 ACC 2014 Guidelines[107]

1. Class I indications ("AVR is recommended")

- Stage D1 – symptomatic patients with a peak velocity ≥4 m/s or a mean gradient >40 mm Hg; this also includes patients who may be asymptomatic at rest but have symptoms during an exercise tolerance test (ETT).
- Stage C2 – patients who are asymptomatic but have high gradients and depressed LV function (EF <50%). As noted above, the Mayo Clinic study showed that these patients have a poor prognosis even with AVR.[122]
- Severe AS (any stage C or D) in a patient undergoing other cardiac surgery with a peak velocity ≥4 m/s or a mean gradient ≥40 mm Hg.
- When the indication for AVR is met, the ascending aorta should be resected if ≥4.5 cm, whether with bicuspid or trileaflet valves.

2. Class IIa indications ("AVR is reasonable")

- Stage C1 – asymptomatic patients with very severe AS with a peak velocity ≥5 m/s or mean gradient ≥60 mm Hg, or with a peak velocity of 4–4.9 m/s and a mean gradient of 50–59 mm Hg with a positive exercise tolerance test. Studies after the 2014 guidelines were published reported superior long-term survival if AVR was performed before the patient became symptomatic.[130]
- Stage D2 – symptomatic patients with an AVA <1 cm^2 but a mean gradient <40 mm Hg with reduced EF. Since the gradient is conditional upon transvalvular flow, these patients are considered to have "low flow, low gradient" severe AS. A DSE should be performed to determine whether poor ventricular function with a low stroke volume is primarily related to afterload mismatch from true severe AS or is due to contractile dysfunction.

i. If dobutamine produces an increase in stroke volume (or cardiac output) with little increase in gradient, the valve area may increase to >1 cm^2, suggesting this may be pseudo-severe AS. However, if both the gradient and cardiac output increase in tandem, the AVA will remain <1 cm^2, confirming severe AS. Patients in this category achieve a significant benefit from AVR.[131]

ii. Confirmation of stage D2 generally requires an increase in the peak velocity to >4 m/s or a mean gradient to >40 mm Hg with dobutamine. However, the validity of the DSE may be limited if dobutamine fails to increase the stroke volume more than 20%. These patients have poor contractile reserve, suggesting that afterload mismatch is not the problem and inferentially that AVR may not improve LV function. However, studies have shown that both surgical aortic valve replacement (SAVR) and TAVR improve LV function independent of contractile reserve and improve long-term survival.[132,133] Interestingly, an elevated BNP level (>550) has been shown to be a very strong predictor of operative mortality, even more important than lack of contractile reserve documented by DSE.[134] Some studies have suggested that DSE has limited value in predicting the severity of AS and outcomes of AVR.[135] Use of the projected AVA (which estimates the AVA at a standardized normal flow rate) can better distinguish pseudo-severe from severe AS and correlates better with observed mortality in patients managed conservatively.[136,137]

- Stage D3 – symptomatic patients with an AVA <1 cm^2 (indexed AVA ≤0.6 cm^2/m^2), a low gradient, normotension, but a normal EF. In addition, a calcified valve with significantly reduced leaflet motion should be present. These patients are considered to have "paradoxical low flow/low gradient" severe AS if the SVI is <35 mL/m^2.[137] Reduced transvalvular flow may produce lower gradients despite the presence of a severely stenotic valve. This may be noted in patients with AF, concomitant MR, and impaired diastolic filling, and may be exacerbated in hypertensive patients with reduced arterial compliance or increased vascular resistance.[112] The prognosis is poor with medical therapy, and both SAVR and TAVR have been shown to improve survival in these patients.[114,138,139] Nonetheless, one study found that the survival of LF/LF patients with normal EF was fairly similar to that of patients with mild–moderate AS and was not influenced by performing an AVR.[140]
- The patient with Stage B moderate AS with a peak velocity of 3–3.9 m/s undergoing other cardiac surgery. Most surgeons would consider performing an AVR for moderate AS with a cutoff around an AVA <1.4 cm^2 to avoid another operation in the next few years. However, with the applicability of TAVR, the surgeon may consider not replacing an aortic valve with an AVA >1.2 cm^2 with a mean gradient in the teens.

3. Class IIb indications ("AVR may be considered") for asymptomatic patients at low surgical risk with severe AS (Class C1) with a peak velocity ≥4 m/s or a mean gradient ≥40 mm Hg if serial testing shows an increase in aortic velocity >0.3 m/s/yr.

F. Indications for AVR per 2017 appropriate use criteria.[141] A 2017 publication from multiple societies reviewed the 2014 criteria noted above as well as the 2017 focused update and assessed the appropriateness of AVR for severe AS (AVA <1 cm^2) in 95 different clinical scenarios, coding them as "appropriate", "may be appropriate", or "rarely appropriate". Assessments were made for patients corresponding to stages C1–2 and D1–3, those with comorbidities or frailty that might alter the procedural approach, and for patients requiring additional surgery (ascending aorta, valve, CABG) or undergoing reoperations. For certain categories, recommendations for surgical AVR (SAVR) or TAVR were made. Some differences from the 2014 criteria noted above include the following:

1. AVR "may be appropriate" for asymptomatic patients with high gradient AS (Vmax 4–4.9 m/s), a negative stress test, and no predictors of symptom onset or rapid progression, such as Vmax >0.3 m/s/yr, severe valve calcification, elevated BNP, or excessive LVH in the absence of hypertension. These stage C1 patients would not be candidates for AVR per the 2014 criteria unless the peak velocity was >5 m/s. However, AVR would be appropriate for these patients in the 2014 and AUC guidelines if the stress test were positive or these predictors were present.
2. AVR "may be appropriate" for asymptomatic patients with LF/LG severe AS with normal EF with a heavily calcified valve. As these patients would be stage C, not stage D3, AVR per the 2014 criteria would only be indicated if these patients were symptomatic and had an SVI <35 mL/m^2.
3. AVR is "appropriate" for symptomatic patients with preserved EF, NF/LG and an AVA <1 cm^2 if they have a heavily calcified valve, the latter being referred to as "a calcified valve with significantly reduced leaflet motion" in the 2014 guidelines. However these guidelines also required a low SVI to qualify for an AVR.
4. AVR was "inappropriate" for patients with an EF of 20–49%, and LF/LG severe AS with no flow reserve on low-dose DSE. Although not specifically addressed in the 2014 guidelines, the literature does suggest that, despite the increased risk, SAVR or preferably TAVR may provide a hemodynamic and clinical benefit to these patients.[132,133]

5. AVR was "inappropriate" for patients with an EF <20% with a mean gradient <20 at rest and no flow reserve. The issue for these patients is whether there might be any clinical improvement after AVR despite lack of contractile reserve if the valve appeared severely stenotic on echo. Surgery would probably be contraindicated due to the high risk, but high risk "salvage" TAVR might be considered if the patient were severely symptomatic, had normal mental status, no other major comorbidities, and understood that the procedure might not provide any benefit.

G. Selection of procedure: TAVR vs. SAVR

1. The clinical trials of TAVR vs. medical therapy and TAVR vs. SAVR have confirmed excellent clinical outcomes for patients with progressively lower STS risk profiles, such that in mid-2019 TAVR was approved in the United States for use in low-risk patients.[142] Comparable results have been noted with the balloon-expandable valves (primarily the Edwards SAPIEN series) and self-expanding valves (primarily the Medtronic CoreValve/Evolut series). Consequently, calculation of the predicted operative risk using the STS risk model, which has been updated to reflect more comorbidities including frailty, has become less important in the selection of the appropriate procedure.
2. Not only have the hemodynamics of TAVR valves proven to be superior to surgical implanted valves with lower transvalvular gradients,[143] but the risk of mortality and morbidity with transfemoral TAVR procedures has been equivalent to if not better than SAVR. The risk of stroke is approximately 2% with the latest generation TAVR valves, and the need for a permanent pacemaker has gradually been declining, now estimated at around 5%, comparable to or perhaps slightly greater than SAVR. Patient recovery is expedited by the less-invasive nature of the procedure, and improvement in the quality of life is better as well. Remaining issues are those of long-term durability of the transcatheter valves if they are to be used in younger patients,[144] successful implantation within bicuspid valves, and use in patients with pure aortic regurgitation, which most likely will be feasible with newer valve designs.
3. AUC for TAVR continue to evolve, so any published recommendation is outdated. The STS-TVT registry tracks implantation data, and TAVR volumes have exceeded SAVRs for several years, and will only increase with the inclusion of more low-risk patients. TAVRs are indicated for the same reasons as SAVRs, but are preferable when the risk is high and the benefit is uncertain.

H. Preoperative considerations

1. Prior to SAVR or TAVR, coronary angiography should be performed in any patient over the age of 40 or in a younger patient with coronary risk factors, angina, or a positive stress test. TAVR can generally be performed in patients without an extensive ischemic burden, but preliminary or simultaneous PCI can be considered if TAVR is selected over SAVR + CABG.
2. Ischemic syndromes in patients with AS require judicious management. Medications that must be used very cautiously are those that can reduce preload (nitroglycerin), afterload (calcium channel blockers), or heart rate (β-blockers), because they may lower cardiac output and precipitate cardiac arrest in a patient with critical AS. The ventricular response to AF must be controlled.
3. Some patients with AS have a history of gastrointestinal bleeding ascribed to colonic angiodysplasia (Heyde's syndrome). This has been associated with acquired type 2A von Willebrand syndrome.[145,146] This develops due to proteolysis of the

largest multimers of von Willebrand factor by shear stress on the blood as it passes through the stenotic valve. Understandably, this is also noted with dysfunctional prosthetic valves.[147] These multimers are important for platelet-mediated hemostasis, so when reduced, they can cause bleeding. Use of preoperative desmopressin (0.3 μg/kg) given after the induction of anesthesia in patients with abnormal platelet function associated with this syndrome has been shown to significantly reduce perioperative blood loss.[148] AVR generally will resolve this hemostatic problem.

4. Dental work should be performed before surgery to minimize the risk of prosthetic valve endocarditis (PVE), unless it is felt to be a prohibitive risk. A study from the Mayo Clinic reported a 3% risk of death within 30 days after dental extraction in patients awaiting surgery.[149]
5. Selection of the appropriate procedure and valve type for surgical AVR depends on a number of factors, including the patient's age, contraindications to long-term anticoagulation, and the patient's desire to avoid anticoagulation. All mechanical valves require lifelong warfarin, as the NOACs do not appear to suffice. Structural valve deterioration of tissue valves is inversely related to patient age and is worse in the presence of renal failure (Figure 1.7). Improvements in valve preservation techniques may improve valve longevity, supporting the use of tissue valves in younger patients. When either severe bioprosthetic stenosis or regurgitation occurs, it may be treated by reoperation or a valve-in-valve TAVR. The latter can often provide superior hemodynamics to even the original valve

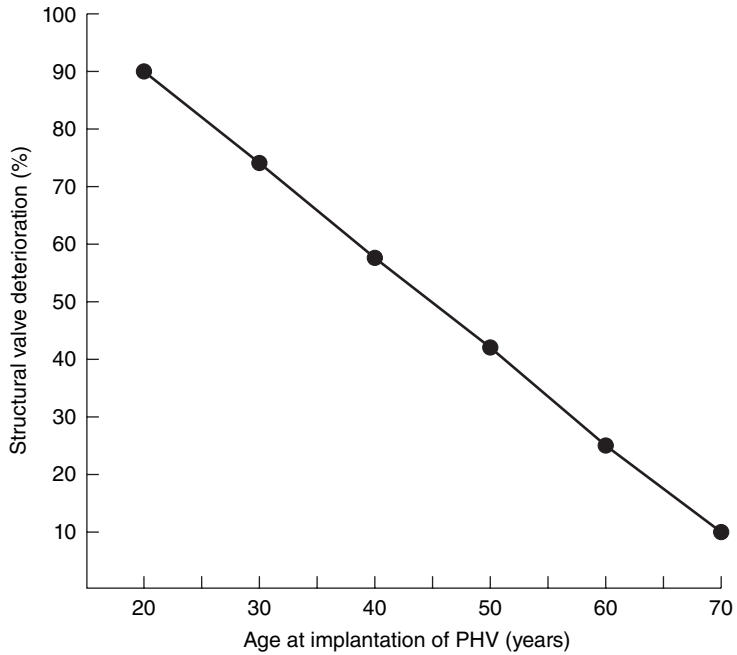


Figure 1.7 • Correlation of patient age with the risk of structural valve deterioration of tissue valves at 15–20 years. (Reproduced with permission from Rahimtoola, *J Am Coll Cardiol* 2010;55:2413–26.)

replacement because many tissue valve frames can be fractured allowing for better expansion of the transcatheter valve within the valve orifice.[150]

6. Selection of valve product for TAVRs is a matter of preference and experience, with potentially lower gradients in the small aortic root with the Medtronic CoreValve Evolut valves, which are constructed of porcine pericardium within a nitinol frame and lie more supra-annular than the Edwards valves.

I. Surgical procedures

1. Aortic valve procedures may be performed through a full median sternotomy incision or through a minimally invasive incision. These include an upper or lower sternotomy with a "J" or "T" incision into the third or fourth intercostal space, or an anterior right second or third interspace incision.[151–153] Cannulation for CPB for minimally invasive approaches can be performed either through the incision or using the femoral vessels. If the latter is planned, a preliminary abdominal-pelvic CT scan should be performed to assess for iliofemoral artery size, tortuosity, and calcification.
2. SAVR with either a tissue or mechanical valve has been the standard treatment for AS (Figure 1.8), but has been superseded by the use of transcatheter valves in most patients.
   a. Mechanical valves of bileaflet tilting disk design have virtually completely replaced single-leaflet tilting disk valves. They require lifelong anticoagulation with warfarin. Valve longevity is contingent on the development of complications such as thrombus formation or pannus ingrowth that impairs leaflet function, or the development of endocarditis.
   b. Tissue valves include porcine and bovine pericardial valves, all of which have various heat or chemical treatments to improve longevity. Rapid deployment valves are often considered to reduce cross-clamp times during complex operations or in older patients. These include the Sorin Perceval valve and the Edwards Intuity valves. They have similar valve leaflets but are designed for implantation with few sutures to expedite implantation. The lower segment of the valve frame may predispose to bundle branch blocks and complete heart block, the latter being noted in about 10% of patients.[154,155]
   c. A stentless valve may be selected to provide a larger effective orifice area and may be placed in the subcoronary position or as a root replacement. Its primary benefit may be noted in the small aortic root (Figure 1.9).[156,157]
   d. The Ross procedure, in which the patient's own pulmonary valve is used to replace the aortic root, with the pulmonary valve being replaced with a homograft (basically a double-valve operation for single-valve disease), is an even more complicated procedure generally reserved for patients younger than age 50 who wish to avoid anticoagulation (Figure 1.10).[158,159]
   e. Homografts are usually reserved for patients with aortic valve endocarditis, although other types of prostheses arguably provide comparable results.[160,161]
   f. An aortic root replacement, usually as a valved conduit, is indicated when the ascending aorta must also be replaced (Figure 1.11). If the sinuses of Valsalva are not dilated, replacing the aortic valve and using a supracoronary graft simplifies the procedure. In younger patients, a commercially available mechanical valved conduit is selected. In older patients, a "bioroot" may be used to avoid anticoagulation. This is constructed by sewing a tissue valve into the proximal end of the Dacron graft.[162]

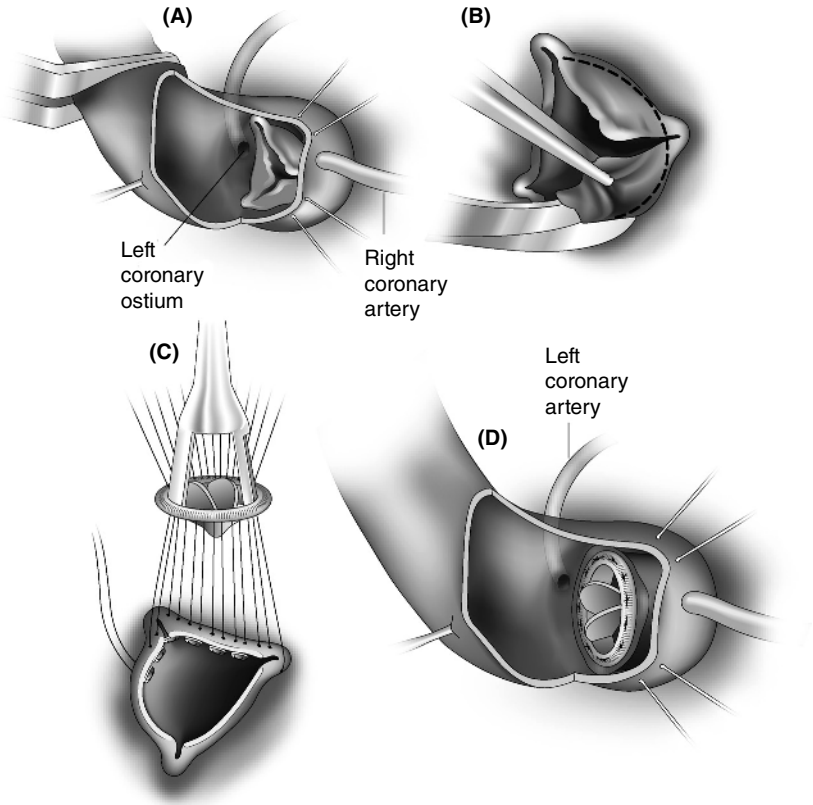


Figure 1.8 • Aortic valve replacement (AVR). (A) A transverse aortotomy incision is made and holding sutures are placed. (B) The valve is excised, and the annulus is debrided and sized. (C, D) Pledgeted mattress sutures are placed through the annulus and through the sewing ring of the valve, the valve is lowered to the annulus, and the sutures are tied. The aortotomy is then closed.

3. Transcatheter aortic valve replacement (TAVR) involves the endovascular placement of a tissue valve mounted on a catheter delivery system. Although numerous valves have been designed and are being evaluated, the two most popular ones are the Edwards SAPIEN series, which is a balloon-expandable bovine pericardial valve (Figure 1.12), and the Medtronic CoreValve/Evolut series, which has a porcine pericardial valve within a nitinol self-expanding valve frame delivered within a sheath (Figure 1.13). Both of these systems can be used for stenotic native valves as well as stenotic or regurgitant bioprosthetic valves ("valve-in-valve" procedure).
   a. A CT scan is an essential component of the preoperative evaluation. The chest imaging will assess the aortic annular area and perimeter to determine the appropriate-sized transcatheter heart valve. The distance from the annulus to the coronary ostia is measured to ensure that native valve displacement does not obstruct the coronary ostia. This is especially important in valve-in-valve procedures. A BASILICA (Bioprosthetic Aortic Scallop Intentional Laceration

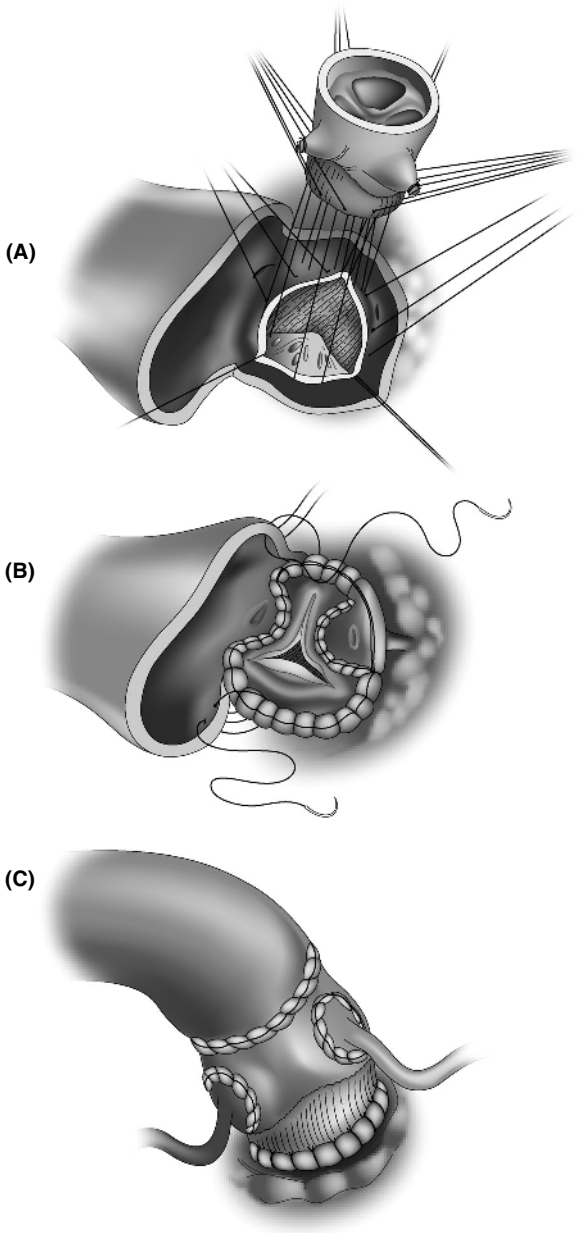


Figure 1.9 • Stentless valves have a larger effective orifice than stented valves, allowing for more regression of LV hypertrophy. (A) The proximal suture line sews the lower Dacron skirt of the prosthesis to the aortic annulus. (B) Subcoronary implantation of a Medtronic Freestyle valve. This requires scalloping of two sinuses with the distal suture line carried out below the coronary ostia. (C) A stentless valve can be used as a root replacement, requiring reimplantation of buttons of the coronary ostia. The distal suture line is an end-to-end anastomosis to the aortic wall.

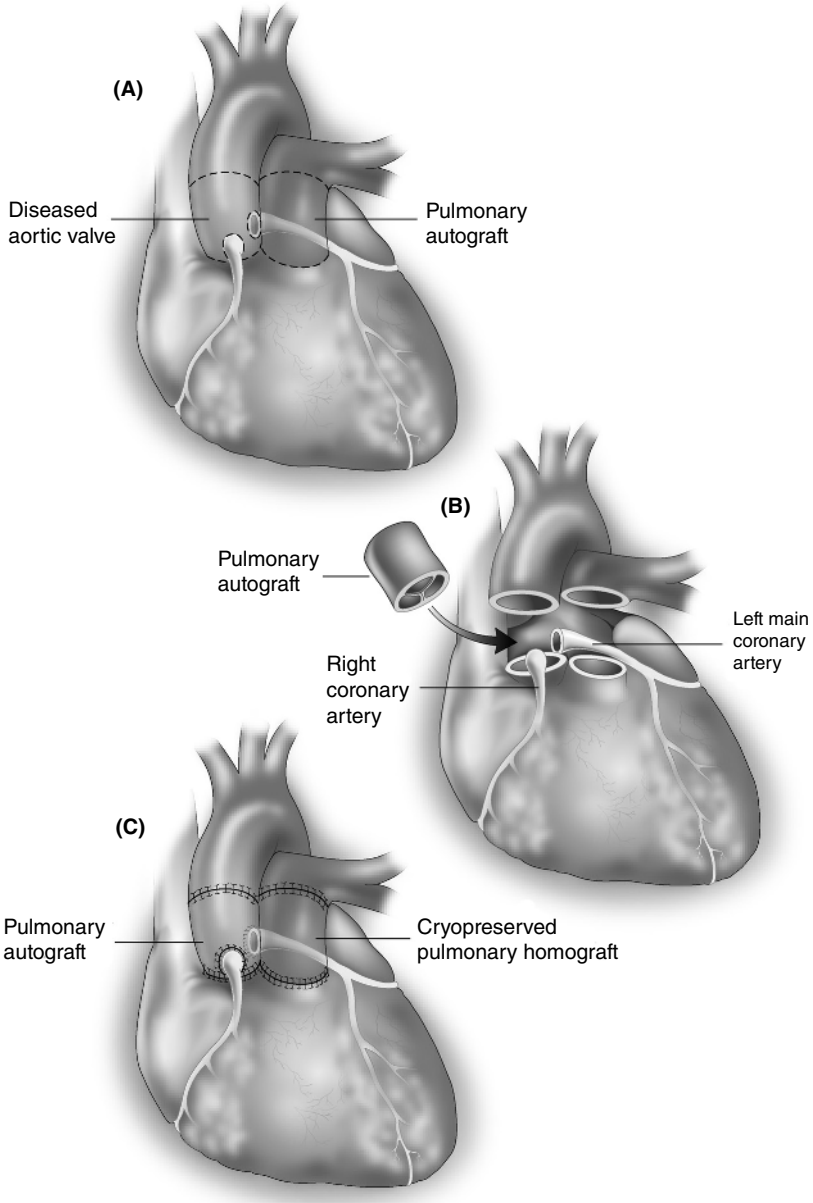


Figure 1.10 • Ross procedure. (A) The aorta is opened and the diseased aortic valve is removed. The pulmonic valve and main pulmonary artery are carefully excised and the coronary arteries are mobilized. (B) The pulmonary autograft is then transposed to the aortic root. (C) The coronary arteries are reimplanted and the RV outflow tract is reconstructed with a cryopreserved pulmonary valved homograft.

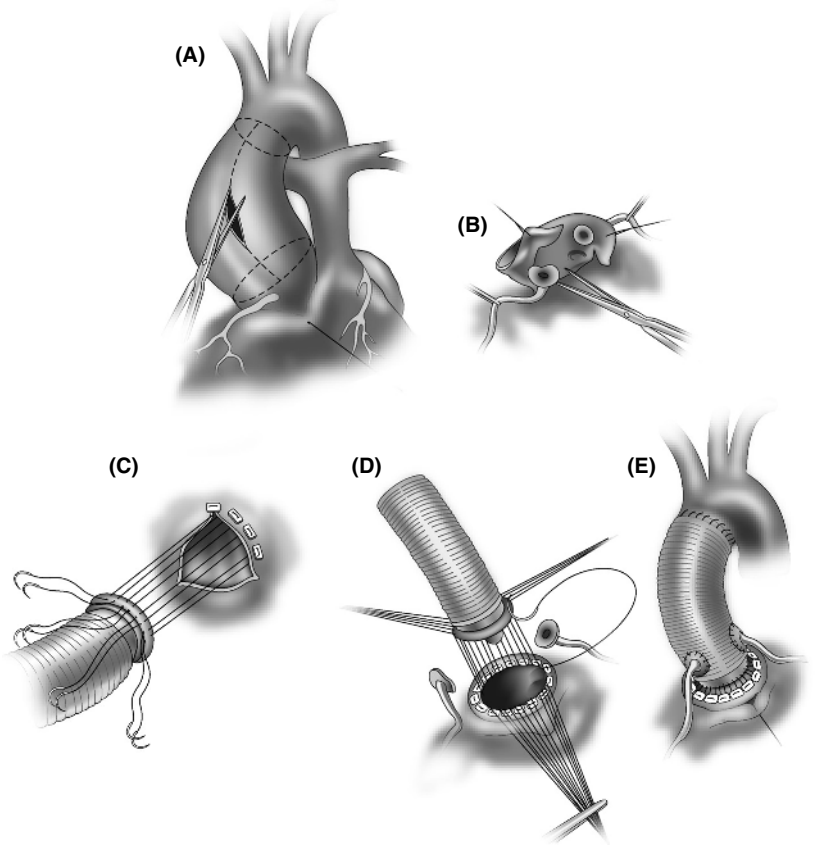


Figure 1.11 • Bentall procedure. (A) The aorta is opened and then divided proximally and distally. (B) Coronary ostial buttons are mobilized. (C, D) A valve incorporated into the proximal end of the conduit is sewn to the aortic annulus. (E) The coronary ostial buttons are reimplanted and the distal suture line is completed.

to prevent Iatrogenic Coronary Artery obstruction) may be necessary in these procedures to avoid coronary ostial obstruction in patients with low coronary ostia. The abdominal-pelvic imaging assesses the size, tortuosity, and calcification of the iliofemoral vessels to determine whether a transfemoral approach is feasible (Figure 2.37, page 163).

b. The procedural risk is lower with a transfemoral approach. If not feasible, subclavian imaging should be evaluated to assess for axillary/subclavian access which can be achieved via cutdown or percutaneously. Additional alternative access sites include transcaval, transaortic through a limited upper sternotomy, transcarotid, and transapical approaches.[163–165] The latter was initially the approach of second choice, but was fraught with more complications, especially in elderly patients.

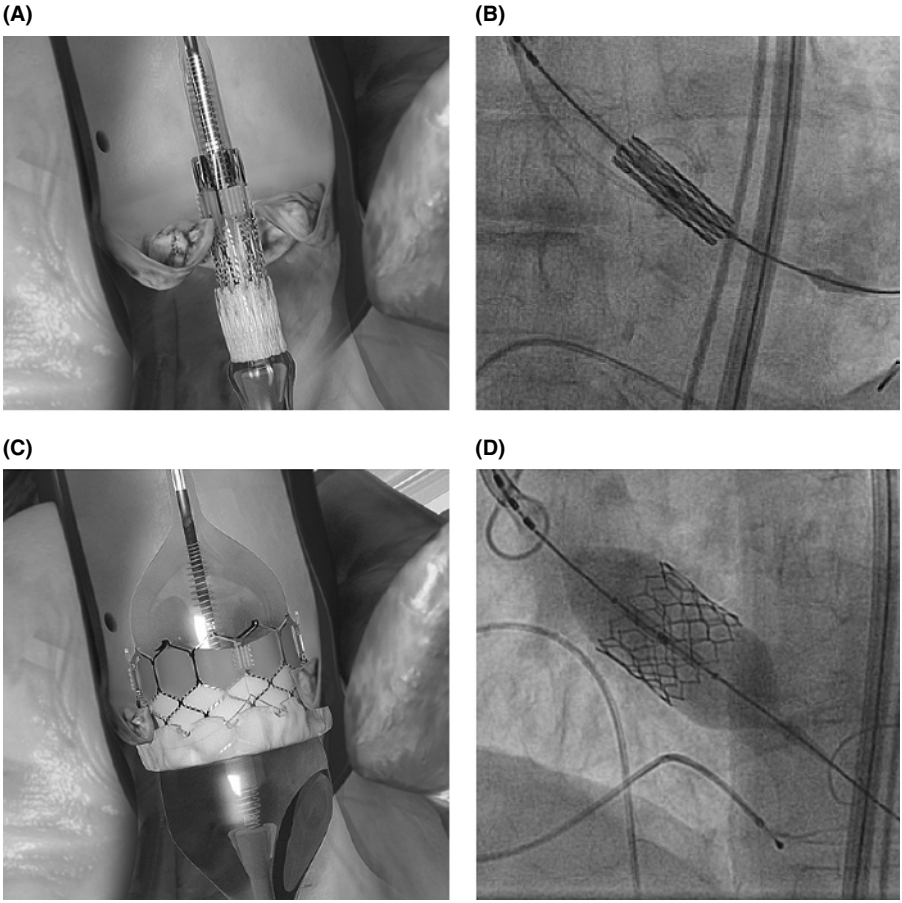


Figure 1.12 • Drawing and fluoroscopic images of a transcatheter aortic valve replacement (TAVR) with an Edwards SAPIEN 3 transcatheter heart valve. (A, B) Initial positioning across the native annulus. (C, D) Complete valve deployment by balloon inflation. (Image courtesy of Edwards Lifesciences (A and C)).

c. Transcatheter valves have less stent frame width than surgical valves and are designed for optimal opening of the leaflets. This produces superior hemodynamics to surgical valves, especially in the small aortic annulus. Clinical outcomes in patients at high, intermediate, and low surgical risk are equivalent, if not superior, to SAVR. The major risks are those of stroke, estimated at around 2%, which might be reduced by use of a cerebral protection device (SENTINEL cerebral protection systems [Boston Scientific Sentinel device]),[166–168] and the necessity for a permanent pacemaker for complete heart block. With less deployment in the LVOT, this risk has been substantially reduced to less than 5%. This risk is greater in patients with a pre-existing right bundle branch block and a left anterior hemiblock.

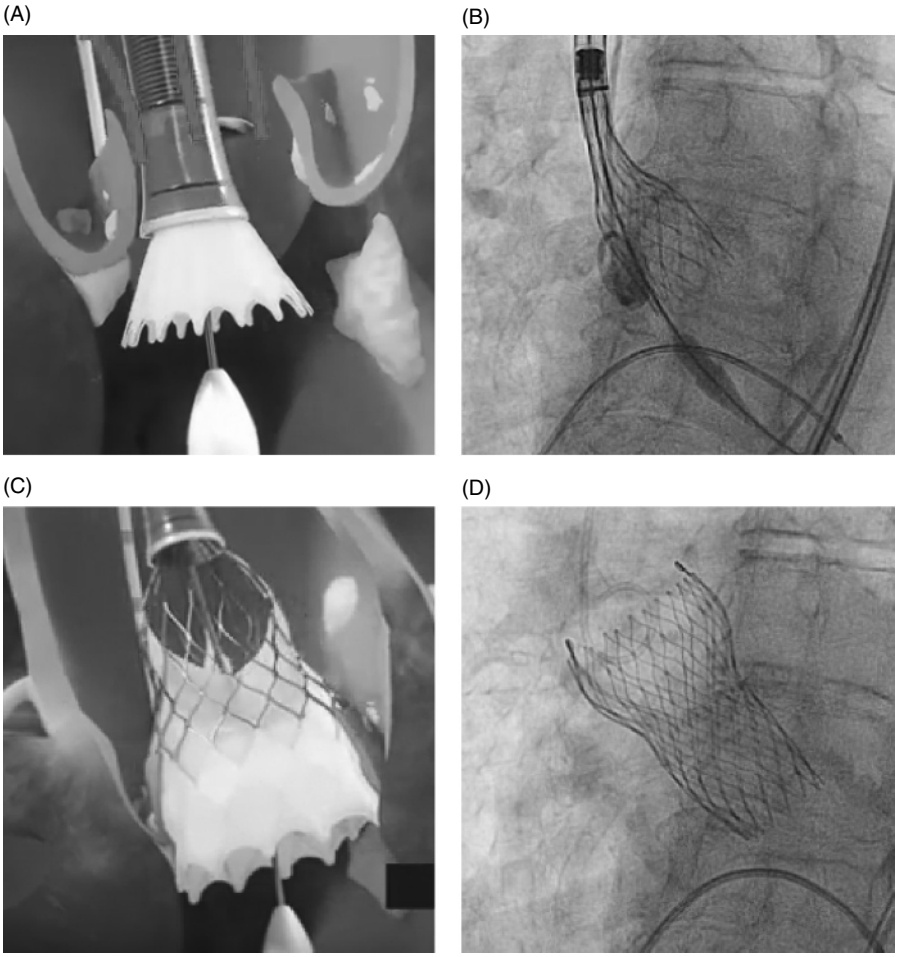


Figure 1.13 • Drawing and fluoroscopic images of a TAVR with a Medtronic Evolut Pro valve. (A, B) Partial self-expansion of the nitinol frame by withdrawal of the constraining sheath. (C, D) Complete valve deployment. (Image courtesy of Medtronic, Inc. (A and C)).

4. Reparative procedures, such as commissurotomy or debridement, have little role in the management of critical AS. However, debridement may be considered in the patient with moderate AS in whom the valve disease is not severe enough to warrant valve replacement, but in whom decalcification may delay surgery for a number of years.

V. Aortic Regurgitation

A. Pathophysiology. Aortic regurgitation (AR) results from abnormalities in the aortic valve leaflets (calcific degeneration, bicuspid valves, destruction from endocarditis) or from aortic root dilatation that prevents leaflet coaptation (idiopathic root dilatation causing annuloaortic ectasia, aortic dissection with cusp prolapse).[106]

Table 1.4 • Stages of Chronic Aortic Regurgitation

Stage A: At risk of AR (bicuspid valve, dilated sinuses, rheumatic heart disease)
Stage B: Progressive AR (mild–moderate AR, normal LV function and dimensions)
Stage C: Asymptomatic severe AR
C1: Asymptomatic with EF ≥50% and LV-ESD ≤50 mm
C2: Asymptomatic with EF ≤50% or LV-ESD >50 mm (indexed LVESD >25 mm/m^2)
Stage D: Symptomatic severe AR with any LVEF, moderate–severe LV dilatation

LV-ESD, left ventricular end-systolic dimension

1. Acute AR usually results from endocarditis or a type A dissection. The ventricle is unable to dilate acutely to handle the sudden increase in regurgitant volume, which increases the LV end-diastolic volume (LVEDV) and pressure (LVEDP), resulting in acute LV failure, cardiogenic shock, and pulmonary edema. Dramatic elevations in filling pressures may occur if acute AR is superimposed on a hypertrophied ventricle. Acute myocardial ischemia may result from increased afterload (LV dilatation), compensatory tachycardia, and a reduction in perfusion pressure as the LVEDP approaches the aortic diastolic pressure. As a result, sudden death may occur.
2. Chronic AR produces pressure and volume overload of the LV, resulting in progressive LV dilatation (increase in LVEDV) with an increase in wall stress, an increase in ventricular compliance, and progressive hypertrophy. Most patients remain asymptomatic for years, even with severe AR, because recruitment of preload reserve and compensatory hypertrophy maintain a normal EF despite the increased afterload. The increased stroke volume maintains forward output and is manifest by an increase in pulse pressure with bounding peripheral pulses. Eventually, increased afterload and impaired contractility lead to LV systolic dysfunction and a fall in EF. Usually at this point, the patient becomes symptomatic with dyspnea. Impairment of coronary flow reserve may cause angina (Table 1.4).
3. Generally, patients with advanced HF symptoms (NYHA class III–IV) or systolic dysfunction with a decreased EF and/or increased LV end-systolic dimension (LVESD) have a higher perioperative mortality rate and compromised long-term survival. Normalization of a depressed EF may occur after surgery when afterload excess is the cause of LV systolic dysfunction and when LV dysfunction is not long-standing. However, patients with prolonged LV dysfunction usually have depressed myocardial contractility and will have a suboptimal result from surgery with persistent LV dysfunction.

B. Diagnosis. Careful monitoring is essential to identify when patients become symptomatic, develop severe AR, and/or have evidence of incipient LV dysfunction. Echocardiography and aortic root aortography at the time of catheterization can delineate the degree of AR (Figure 2.8, page 138). Echo is valuable in assessing valve morphology, aortic root size, LV cavity dimensions, wall thickness, and systolic function. Color and pulsed wave Doppler findings can be used to assess the degree of AR (Table 1.5).

Table 1.5 • Echocardiographic Findings of Moderate and Severe Aortic Regurgitation

	Moderate	Severe
Doppler jet width	25–64% of LVOT	≥65% of LVOT
Vena contracta	0.3–0.6 cm	>0.6 cm
Diastolic flow reversal	no	yes
Regurgitant volume	0–59 mL/beat	≥60 mL/beat
Regurgitant fraction	30–49%	≥50%
ERO	0.1–0.29 cm^2	≥0.3 cm^2
LV dilatation	no	yes
Pressure half-time	200–500 ms	<200 ms

ERO, effective regurgitant orifice
Adapted with permission from Nishimura et al., *Circulation* 2014;129:e521–643.[107]

C. Indications for surgery (based on 2014 ACC guidelines)[107]

1. **Class I Indication** ("Surgery is recommended")
   a. Stage D – symptomatic severe AR, irrespective of LV systolic function. Once the heart becomes severely dilated, irreversible myocardial damage may already have occurred and the long-term results of surgery are suboptimal. The estimated mortality rate is >10%/year for patients with angina and >20%/year for patients with CHF without surgery.[106] Some patients are symptomatic with moderate AR when there is a reduced EF, LV dilatation, and a markedly elevated LVEDP.
   b. Stage C2 – asymptomatic severe AR with LVEF <50% at rest unless there is another cause for the decreased LVEF. These patients are already in a decompensated phase and develop symptoms at a rate of 25%/year. Prompt surgical intervention is indicated because long-term survival is compromised with a lower EF and LV dilatation (LV-ESD ≥40mm) due to more advanced remodeling.[169] If the etiology of the decreased EF is unrelated to the AR (i.e. a prior infarction, infiltrative disease, dilated cardiomyopathy), LV function may not improve and surgery may not be indicated.
   c. AVR is indicated for severe AR if cardiac surgery is being performed for another indication.
2. **Class IIa indication ("Surgery is reasonable")**
   a. Asymptomatic severe AR with normal EF but LVESD >50 mm or indexed LVESD >25 mm/m^2. Evidence of LV dilatation also indicates a decompensated phase with a nearly 20% annual risk of developing systolic dysfunction once the LVESD exceeds 50 mm and a 25% risk once it exceeds 55 mm.

b. AVR is reasonable with moderate AR if other cardiac surgery is being performed for another indication

3. Class IIb indication ("Surgery may be considered")

a. Stage C1 – Asymptomatic severe AR with normal EF but with progressive severe LV dilatation (left ventricular end-diastolic dimension [LVEDD] >65 mm). These patients are at high risk for sudden death.

4. Other comments

a. Serial echocardiograms are important to identify early evidence of ventricular decompensation, since survival without surgery and the long-term prognosis after surgery are influenced by the degree of LV systolic dysfunction. Asymptomatic patients in stage C1 with an LVESD of 40–49 mm have about a 4% annual risk of developing symptoms, LV dysfunction or death, yet about 25% of patients may develop LV dysfunction or die before they become symptomatic. Thus, surgery is indicated at the first sign of ventricular decompensation, which is generally when the LVEF falls below 50% or the LVESD exceeds 50 mm.

b. The utility of stress testing in asymptomatic patients is not well defined. High-risk findings include development of symptoms, exercise capacity <85% of predicted, absence of contractile reserve with borderline hemodynamic indications for surgery (LVEF 50–55% or LVESD approaching 50 mm), and tricuspid valve annular plane systolic excursion <21 mm (a sign of RV dysfunction). These findings may identify patients who are truly not asymptomatic and those with subclinical LV dysfunction who might benefit from earlier surgery. A fall in ejection fraction during stress testing has unclear prognostic significance. None of these considerations was included in the 2014 guidelines.

c. Aortic valve endocarditis producing acute AR and hemodynamic compromise, or the presence of an annular abscess or conduction abnormalities are indications for urgent, if not emergent surgery (see section IX, pages 61–62). The presence of residual vegetations after an embolic event, large mobile vegetations, or persistent bacteremia are other indications for early surgery.

D. Preoperative considerations

1. Systemic hypertension may be treated with ACE inhibitors, ARBs, amlodipine, β-blockers, diuretics, and aldosterone receptor antagonists (spironolactone, eplerenone). Reducing the blood pressure may increase forward flow and reduce the degree of regurgitation, but excessive afterload reduction may reduce diastolic coronary perfusion pressure and exacerbate ischemia. β-blockers for control of ischemia must be used cautiously because a slow heart rate increases the amount of regurgitation. They are contraindicated in acute AR because they will block the compensatory tachycardia. ACE inhibitors and ARBs are usually held the morning of surgery to prevent vasoplegia, although this remains controversial.

2. Coronary angiography is indicated before surgery for virtually all patients to identify coronary dominance and potential stenoses that may need to be addressed.

3. Placement of an IABP for control of anginal symptoms is contraindicated.

4. As for all non-emergent valve patients, dental work should be completed before surgery.

5. Contraindications to warfarin should be identified so that the appropriate valve can be selected.

E. Surgical procedures

1. AVR has traditionally been the procedure of choice for adults with AR. This may involve use of a tissue or mechanical valve, the Ross procedure, or a cryopreserved homograft. Studies are underway to determine the feasibility of TAVR for pure AR.[170]
2. Aortic valve repair, involving resection of portions of the valve leaflets and re-approximation to improve leaflet coaptation (especially for bicuspid valves), often with a suture annuloplasty, has been performed successfully. This is valuable in the younger patient in whom any valve-sparing procedure is preferable to valve replacement.[171]
3. A valved conduit (Bentall procedure) is placed if an ascending aortic aneurysm ("annuloaortic ectasia") is also present (Figure 1.11). In younger patients, manufactured mechanical valved conduits are preferable, but if there is a strong indication for avoiding anticoagulation, a "bioroot" created by sewing a tissue valve into a graft can easily be accomplished.[172] Alternatively, a Medtronic Freestyle stentless valve can be placed with distal graft extension to replace an aortic aneurysm.[173]
4. Aortic valve-sparing root replacement is feasible in some patients with significant AR if adequate remodeling of the root can be accomplished, and it can be used successfully even in patients with bicuspid valves or Marfan syndrome (Figure 1.14). The aorta is resected, sparing the commissural pillars. A graft is then sewn at the subannular level, the aortic valve is resuspended within the graft, and the aortic remnants are sewn to the graft. Coronary ostial buttons are then sewn to the graft.[174–176]

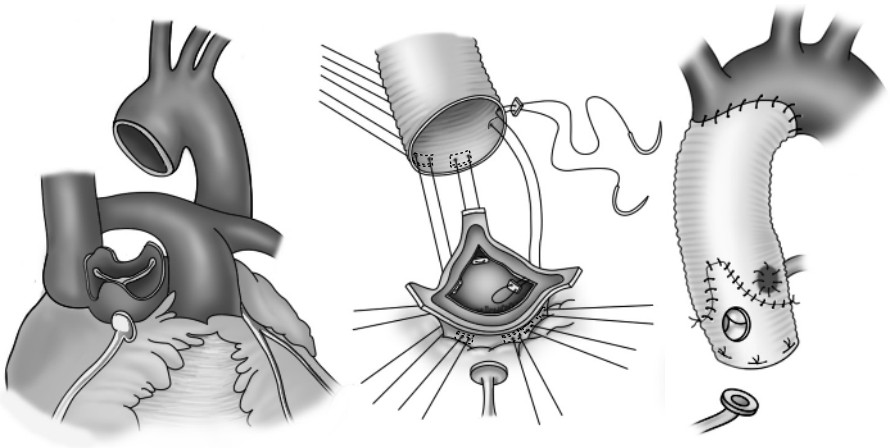


Figure 1.14 • Aortic valve-sparing root replacement. (A) The aortic root is resected, sparing the pillars that support the commissures and the coronary arteries are mobilized as buttons. (B) Sutures are placed at the subannular level in a horizontal plane and passed through a tubular graft. (C) The graft is tied down and the aortic valve is resuspended by suturing the commissural posts and the base of the sinuses to the inside of the graft. The coronary buttons are reimplanted and the distal anastomosis is completed.

VI. Mitral Stenosis

A. Pathophysiology.[106] Mitral stenosis (MS) occurs nearly exclusively as a consequence of rheumatic fever. Thickening of the valve leaflets with commissural fusion and thickening and shortening of the chordae tendineae gradually reduce the size of the mitral valve orifice and the efficiency of LV filling. The increase in the diastolic transmitral gradient increases the left atrial and pulmonary venous pressures. Initially, left atrial size and compliance increase, and symptoms may be brought on by exercise or rapid heart rates, such as with AF. As the MS becomes severe, the left atrium remodels, and symptoms of heart failure, including dyspnea, orthopnea, and hemoptysis, may occur. An adaptive measure that can minimize symptoms is a decrease in pulmonary microvascular permeability and the development of pulmonary arteriolar vasoconstriction and thickening, which leads to pulmonary hypertension (PH). This may then lead to right-sided HF and functional tricuspid regurgitation (TR). As the severity of MS and PH worsen, the cardiac output is compromised at rest and fails to increase with exercise. The development of AF further increases LA pressures, decreases ventricular filling, and compromises cardiac output. It may predispose to left atrial thrombus formation and systemic thromboembolism (Table 1.6).

B. Natural history. MS is a slowly progressive process which may not produce symptoms for several decades. The minimally symptomatic patient has an 80% 10-year survival, but once symptoms develop, survival is very poor with a 10-year survival in some of the early natural history studies of only 33% and 0% for patients in NYHA classes III and IV, respectively.[177] Severe PH (pulmonary artery [PA] pressure >80 mm Hg) is associated with a mean survival of less than three years. Therefore, intervention should be considered when the patient develops class II–III symptoms.

C. Diagnosis. The severity of MS is determined primarily by echocardiography and can also be defined by cardiac catheterization (Table 1.7).

1. Echocardiography measures the mean diastolic gradient and, by the continuity equation, determines the mitral valve area (MVA). Echo also measures the diastolic pressure half-time, estimates the PA pressure from the tricuspid velocity jet, and can evaluate valve morphology using an echo score (Table 1.7).[178] This assesses leaflet mobility, thickening, calcification, and subvalvular thickening and can be used to determine whether the valve is amenable to balloon valvuloplasty.
2. Cardiac catheterization allows for calculation of the MVA from the cardiac output and the transvalvular mean gradient (pulmonary capillary wedge pressure [PCWP] minus the LV mean diastolic pressure). The PA pressure is measured by right-heart catheterization.

Table 1.6 • Stages of Mitral Stenosis

Stage A: At risk of MS (mitral valve doming during diastole)
Stage B: Progressive MS (rheumatic valve changes, mitral valve area [MVA] >1.5 cm^2, normal PA pressures, mild–moderate LA enlargement, pressure half-time <150 ms
Stage C: Asymptomatic severe MS
Stage D: Symptomatic severe MS – decreased exercise tolerance, exertional dyspnea

Table 1.7 • Echocardiographic and Hemodynamic Abnormalities in Severe Mitral Stenosis

Commissural fusion and diastolic doming of leaflets
MVA ≤1.5 cm^2 (≤1.0 cm^2= very severe MS)
Pressure half-time ≥150 ms (≥220 ms = very severe MS)
Severe LA enlargement
PA systolic pressure >30 mm Hg
Note that gradients are utilized to measure the MVA, but are not that useful in the determination of severity.
Right heart catheterization can quantitate mean pulmonary artery pressures:
mild PAH: mean PAP >25–40 mm Hg
moderate PAH: mean PAP 41–55 mm Hg
severe PAH: mean PAP ≥55 mm Hg

PAP, pulmonary artery pressure; PAH, pulmonary artery hypertension
Adapted with permission from Nishimura et al., *Circulation* 2014;129:e521–643.[107]

$$\text{MVA} = \frac{\text{CO}/(\text{DFP} \times \text{HR})}{37.7 \times \sqrt{\text{mean gradient}}}$$

where:

MVA = mitral valve area in cm^2 (normal = 4–6 cm^2)
DFP = diastolic filling period/beat
mean gradient = PCWP – LV mean diastolic pressure

3. Exercise stress echocardiography is helpful in assessing the physiologic severity of disease in patients whose symptoms appear inconsistent with the degree of MS.[179] Exercise will increase the heart rate and decrease the diastolic filling time. In patients with significant MS, this will increase the mean gradient and/or pulmonary artery pressures. Hemodynamically significant MS, an indication for intervention, includes an exercise-induced increase in the mean gradient to >15 mm Hg (>18 mm Hg if a dobutamine stress echo is performed), or an increase in the PCWP to >25 mm Hg. Another high-risk finding is a rise in the RV systolic pressure to >60 mm Hg at peak exercise, although that is not included in the guidelines.

D. Indications for intervention[107]

1. **Percutaneous** mitral balloon valvuloplasty (PMBV) is the procedure of choice for patients with an indication for intervention if valve morphology is favorable by echo score. This procedure generally results in a doubling of the valve area and a 50% reduction in the mean gradient, with excellent long-term results. Mitral valve surgery is indicated when PMBV is contraindicated or not feasible due to unfavorable valve morphology, left atrial thrombus, or 3–4+ MR.[180,181]

2. **Class I indications**
   a. Stage D – PMBV is recommended for symptomatic patients with severe MS (MVA <1.5 cm^2) and favorable anatomy.
   b. Stage D – mitral valve surgery is indicated in NYHA class III–IV patients with severe MS if not high risk and not a candidate for PMBV.
   c. Stage C or D – concomitant mitral valve surgery is indicated for severe MS when cardiac surgery is performed for another indication.
3. **Class IIa indications**
   a. Stage C – PMBV is reasonable for asymptomatic patients with very severe MS (MVA <1.0 cm^2).
   b. Stage D – mitral valve surgery is reasonable for patients in class III–IV with severe MS undergoing other cardiac surgery.
4. **Class IIb indications**
   a. Stage C – PMBV may be considered for asymptomatic patients with severe MS (MVA <1.5 cm^2) and favorable anatomy with new onset of AF.
   b. Stage B/D – PMBV may be considered for symptomatic MS with a mitral valve >1.5 cm^2 if there is hemodynamically significant MS during exercise stress testing.
   c. Stage D – PMBV may be considered for NYHA class III–IV with severe MS with suboptimal anatomy for PMBV when surgery is considered too high risk
   d. Concomitant mitral valve surgery may be considered for moderate MS (MVA 1.6–2.0 cm^2) if undergoing other cardiac surgery.
   e. Mitral valve surgery with excision of the left atrial appendage may be considered for any patient in stage C or D who has had recurrent embolic events on adequate anticoagulation.

E. Preoperative considerations

1. Hemodynamic performance is frequently compromised by a low cardiac output state, which can be worsened by the presence of AF. A rapid ventricular response will shorten the diastolic filling period, reduce LV preload, and elevate LA pressures. Thus, the ventricular response to AF is best controlled in the perioperative period by β-blockers or calcium channel blockers. There is usually a delicate balance between fluid overload, which can precipitate pulmonary edema, and hypovolemia from aggressive diuresis, which can compromise renal function when the cardiac output is marginal. Thus, preload must be adjusted judiciously to ensure adequate LV filling across the stenotic valve.
2. Many patients with long-standing MS are cachectic and at increased risk for developing respiratory failure. Aggressive preoperative diuresis and nutritional supplementation may reduce morbidity in the early postoperative period.
3. Warfarin used for AF, left atrial thrombus, or a history of systemic embolism should be stopped four days before surgery. Since most patients with MS and AF are considered at high risk for embolization, outpatient LMWH may be prescribed as a bridge, but must be stopped 24 hours before surgery. Admission for unfractionated heparin the day before surgery may be considered once the international normalized ratio (INR) falls below the therapeutic range. The NOACs (dabigatran, apixaban, rivaroxaban) should not be used in patients with rheumatic MS.

F. Surgical procedures

1. Closed mitral commissurotomy has been supplanted by PMBV, which produces superior results. Either should be considered in the pregnant patient with critical MS in whom CPB should be avoided.
2. Open mitral commissurotomy is performed if PMBV is not considered feasible or there is evidence of left atrial thrombus. It produces better hemodynamics than either a PMBV or a closed commissurotomy and is associated with improved long-term event-free survival, especially in patients with high echo scores or AF.[180–183] Although recurrent symptoms are noted in 60% of patients after nine years, most symptoms are related to the development of MR or CAD, and not to recurrent MS.[106]
3. Mitral valve replacement (MVR) is indicated if the valve leaflets are calcified and fibrotic or there is significant subvalvular fusion (Figure 1.15).
4. Transcatheter treatment of MS is in its infancy. Transcatheter "valve-in-valve" procedures using aortic transcatheter heart valves have been used to treat bioprosthetic MS or regurgitation.[184,185] If imaging suggests that leaflet displacement may produce LVOT obstruction, a LAMPOON procedure (Laceration of the Anterior Mitral leaflet to Prevent lvOt ObstructioN) may be necessary. Use of these valves for MS associated with very heavy mitral annular calcification ("valve-in-MAC") has been performed, but with high mortality rates.[186] Routine transcatheter MVR with specifically designed valves has been accomplished and may eventually see more widespread use.[184]
5. Patients with a duration of AF exceeding six months will most likely remain in that rhythm postoperatively. Therefore, a Maze procedure should be considered in a patient with either paroxysmal or persistent AF. This should also include exclusion of the left atrial appendage by various techniques. The "cut and sew" Cox-Maze procedure has been replaced by use of energy sources (usually radiofrequency and cryoablation) that can be applied to create transmural ablation lines in well-described patterns to ablate this arrhythmia with fairly good success rates (see section XIII, pages 84–89). It is less likely to be successful when the left atrial dimension exceeds 6 cm.[187,188]
6. Functional TR usually improves after left-sided surgery due to a reduction in pulmonary vascular resistance, but is more likely to persist or progress in patients with AF, large atria, or moderate TR. Since moderate TR often progresses to severe TR, which may compromise long-term survival, tricuspid valve repair is recommended for patients with moderate or severe TR or tricuspid annular dilatation.[189,190] Further comments on TV repair during surgery for MR are noted on pages 57–58.

VII. Mitral Regurgitation

A. Pathophysiology. Mitral regurgitation (MR) has been classified as primary (degenerative) or secondary (functional) depending on the pathologic changes involved.[106,107,191]

1. Primary MR usually results from myxomatous change or fibroelastic deficiency of the valve leaflets causing redundancy, along with chordal elongation or rupture. This results in leaflet prolapse and flail and is also commonly associated with annular dilatation. Rheumatic changes can cause leaflet distortion and chordal damage. Endocarditis is usually associated with the formation of vegetations, leaflet deformity, or perforation.

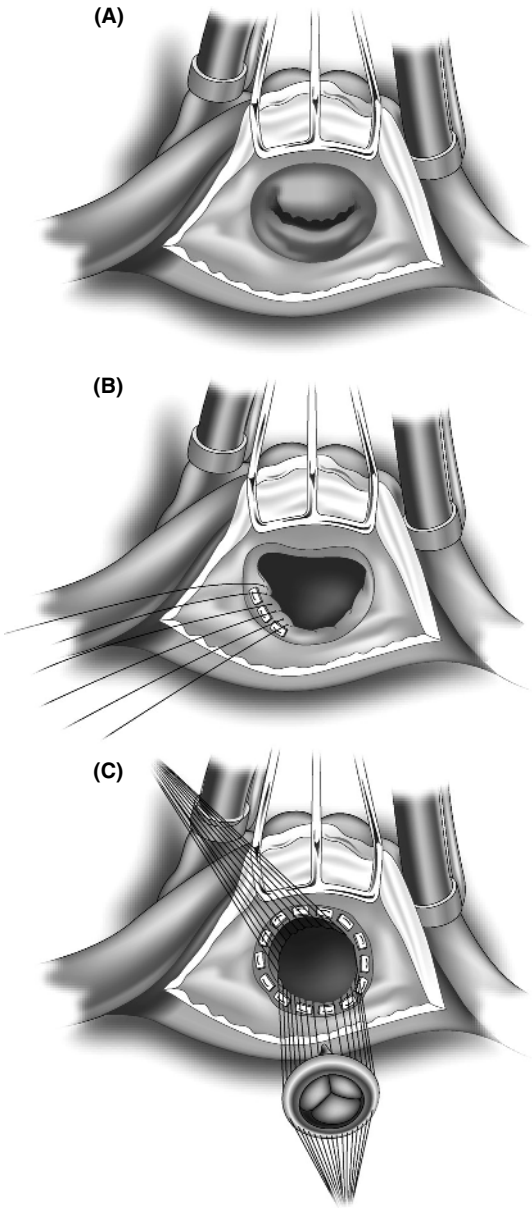


Figure 1.15 • Mitral valve replacement (MVR) via the posterior approach. (A) The left atrium is opened behind the intra-atrial groove and the retractor arms are positioned. Although both leaflets may be retained, the anterior leaflet is usually resected. (B) The posterior leaflet should be retained and is imbricated into the suture line. (C) Pledgeted mattress sutures are placed through the annulus, through or around the valve tissue, and into the sewing ring. The valve is then tied into position. The left atrial appendage may be oversewn from inside the left atrium.

2. Secondary or functional MR is associated with LV dysfunction, most commonly following an infarction, but also in association with dilated or hypertrophic cardiomyopathies. LV remodeling with a change in LV geometry and papillary muscle displacement may cause apical leaflet tethering as well as annular dilatation resulting in failure of the mitral leaflets to coapt properly, resulting in MR. The prognosis is worse with secondary MR because the MR is the result of a ventricular problem rather than a primary leaflet or chordal problem.
   a. The term "ischemic MR" has been applied to most cases of secondary MR caused by coronary disease. The spectrum of "ischemic MR" includes acute MR from infarct-related acute papillary muscle rupture or ischemic dysfunction of the ventricular wall below the papillary muscles as well as chronic secondary MR from prior myocardial damage.
   b. Patients with long-standing AF and those with restrictive cardiomyopathies (amyloid) may develop "atrial functional MR" when severe LA dilatation causes pure annular dilatation.[191]

B. Clinical presentation

1. Acute MR usually results from myocardial ischemia, an acute MI with papillary muscle rupture, endocarditis, or from idiopathic chordal rupture. Acute LV volume overload develops with a reduction in forward output and new-onset regurgitant flow into a small noncompliant left atrium. This may result in both cardiogenic shock and acute pulmonary edema.
2. Chronic MR is a condition of volume overload that is characterized by a progressive increase in compliance of the left atrium and ventricle, followed by a progressive increase in LVEDV as the LV dilates. Some degree of hypertrophy accompanies LV dilatation to normalize LV systolic wall stress. The increase in preload increases overall stroke volume and maintains forward cardiac output. At the same time, there is a decrease in afterload due to ventricular unloading into the left atrium which will normalize systolic wall stress. In the compensated phase, the ejection fraction will usually increase as contractility is also maintained. Patients are usually asymptomatic at this point and may remain so even as ventricular decompensation occurs. An EF in the low–normal range usually reflects some degree of contractile dysfunction. Eventually, prolonged volume overload causes more LV dilatation, significant contractile dysfunction, and an increase in afterload, which lowers the ejection fraction. This results in an increase in end-systolic volume with less forward output, and elevated filling pressures which worsen symptoms of HF.

C. Diagnostic considerations. The progression of MR and assessment of LV dimensions and function should be followed by serial echocardiograms to identify when an intervention should be undertaken to optimize the clinical outcome.

1. Transesophageal echocardiography (TEE) with 3D imaging is the best technique to quantitate the severity of MR and identify its mechanism, and it also assesses LV function and provides an estimate of PA pressure. It can define whether MR is primary (degenerative) with leaflet prolapse from chordal prolongation or rupture, or secondary (functional) on the basis of a dilated annulus or enlarged LV with apical tethering of the leaflets. Generally, single-leaflet prolapse or tethering produces eccentric jets (Figures 2.22 and 2.23), whereas annular dilatation causes central MR (Figure 2.24). TEE assessment is invaluable to the surgeon in helping to determine whether a valve can be repaired, what type of repair may be necessary, or whether replacement is indicated from the outset (Tables 1.8 and 1.9).

Table 1.8 • Stages of Primary Mitral Regurgitation

Stage A: At risk of MR

Stage B: Progressive MR

1. Severe prolapse with normal coaptation
2. Rheumatic changes with leaflet restriction and loss of central coaptation
3. Prior infective endocarditis
4. Central jet MR 20–40% of LA or late systolic eccentric jet of MR
5. VC <0.7 cm, RV <60 mL, RF <50%, ERO <0.4 cm^2
6. Mild LA enlargement, no LV enlargement, normal PA pressures

Stage C: Asymptomatic severe MR

Stage C1 – LVEF >60% and LVESD <40 mm

Stage C2 – LVEF ≤60% and LVESD ≥40 mm

1. Severe prolapse with loss of coaptation or flail leaflet
2. Rheumatic changes with leaflet restriction and loss of central coaptation
3. Prior IE
4. Central jet MR >40% of LA or holosystolic eccentric jet of MR
5. VC ≥0.7 cm, RV ≥60 mL, RF ≥50%, ERO ≥0.4 cm^2
6. Moderate to severe LA enlargement
7. LV enlargement
8. Pulmonary hypertension at rest or with exercise

Stage D: Symptomatic severe MR - same findings as stage C with HF symptoms (decreased exercise tolerance, exertional dyspnea)

IE, infective endocarditis; VC, vena contracta; RV, regurgitant volume; RF, regurgitant fraction; ERO, effective regurgitant orifice; LVESD, left ventricular end-systolic dimension

Adapted with permission from Nishimura et al., *Circulation* 2014;129:e521–643.[107]

Table 1.9 • Stages of Secondary Mitral Regurgitation

Stage A: At risk of MR

Stage B: Progressive MR

1. RWM abnormalities with mild mitral leaflet tethering
2. Annular dilatation with mild loss of central coaptation
3. RWM abnormalities, LV dilatation, and systolic dysfunction due to primary myocardial disease
4. ERO <0.4 cm^2, RV <60 mL, RF <50%

Stage C: Asymptomatic severe MR

1. RWM abnormalities and/or LV dilatation with severe mitral leaflet tethering
2. Annular dilatation with severe loss of central coaptation
3. RWM abnormalities, LV dilatation, and systolic dysfunction due to primary myocardial disease
4. ERO ≥0.40 cm^2, RV ≥60 mL, RF ≥50%

Stage D: Symptomatic severe MR – same findings as stage C with HF symptoms (decreased exercise tolerance, exertional dyspnea) that persists after revascularization and appropriate medical therapy

Hemodynamic parameters to define severe MR were modified in the 2017 AHA/ACC focused update to be identical to those of severe primary MR.

Adapted with permission from Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin III JP, Fleisher LA, Jneid H, Mack MJ, McLeod CJ, O'Gara PT, Rigolin VH, Sundt III TM, Thompson A. 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease. *J Am Coll Cardiol* 2017, doi: 10.1016/j.jacc.2017.03.011.

a. Both color flow Doppler and quantitative parameters, such as calculation of the effective regurgitant orifice area (EROA), regurgitant fraction (RF), and regurgitant volume (RV) are important to appropriately assess the severity of MR.[191]

b. The presence of LV or LA dilatation in primary MR is consistent with severe MR, whereas lack of LA or LV dilatation suggests that the MR is not severe.

c. The degree of MR can be difficult to determine in some cases of secondary MR, because findings such as a dilated LA and LV and systolic blunting of pulmonary venous flow may be related to an underlying cardiomyopathy. Furthermore, the shape of the regurgitant orifice in secondary MR is crescentic and may lead to an underestimation of the EROA.[191]

d. A discrepancy is often noted between the degree of MR identified preoperatively in the awake patient and that assessed under general anesthesia, which alters systemic resistance and loading conditions. Thus, a preoperative TEE is important to quantitate the degree of MR and define the precise anatomic mechanism for the MR. However, the use of sedation for a preoperative TEE may also lessen the degree of MR to some extent.

2. Cardiac magnetic resonance (CMR) imaging is helpful in determining the severity of MR when TEE is inconclusive. It is considered more accurate for quantitating the RV and RF as well as LV volumes and LVEF.[191]

3. Left ventriculography may be used to assess LV function and the degree of MR, but it is frequently insensitive in assessing its severity, which may depend on catheter position, the amount and force of contrast injection, the size of the left atrium or ventricle, and the presence of arrhythmias or ischemia.

D. Indications for intervention for acute MR

1. Acute MR due to papillary muscle rupture usually produces the picture of HF or cardiogenic shock and mandates emergency surgery prior to the development of multisystem organ failure.

2. Active infective endocarditis producing severe MR with hemodynamic compromise is a class I indication for urgent surgery.

E. Indications for intervention in chronic primary MR[107,191–193]

1. Class I indications
   - Stage D – symptomatic, severe MR, LVEF >30%
   - Stage C2 – asymptomatic, severe MR, LVEF 30–60% and/or LVESD ≥40 mm
   - Chronic severe MR if undergoing another cardiac procedure
   - Mitral valve repair is preferable to MVR if feasible in all of the above categories

2. Class IIa indications
   - Stage C1 – mitral valve repair is reasonable for asymptomatic, severe MR, LVEF >60%, and LVESD <40 mm if there is a 95% likelihood of successful repair, or for new onset of AF or resting PA systolic pressure >50 mm Hg if there is a "high likelihood of repair". This recommendation recognizes numerous reports that have demonstrated that mitral valve repair in asymptomatic patients with severe MR improves long-term survival.[194–197] However, it also implies that if a mitral valve repair may not be feasible, these patients should be followed with periodic monitoring for clinical symptoms or hemodynamic deterioration prior to offering surgery.

- Stage C1 – mitral valve surgery is also reasonable if there is a progressive increase in LV size or a decrease in EF on serial imaging studies. Thus, if the LVEF is decreasing yet still above 60% or the LVESD is approaching 40 mm, offering surgery is reasonable. This updated recommendation was based on concern that LV systolic dysfunction may already be present once these parameters have been reached, and earlier surgery may optimize outcomes.[191]
- Concomitant mitral valve repair is reasonable for chronic moderate MR at the time of other cardiac surgery.

3. Class IIb indications
   - Stage D – mitral valve surgery (repair or replacement) can be considered for symptomatic, severe MR with an EF ≤30%. These are higher risk patients due to severe systolic dysfunction, and long-term outcomes are poor.
   - Stage D – Transcatheter mitral valve repair ("MitraClip") can be considered for class III–IV patients with severe MR and favorable anatomy for repair when surgical risk is prohibitive.[198] Generally, this procedure is considered for patients with a high surgical risk exceeding 6%. The initial indication for this approach was degenerative MR, but was subsequently approved for patients with functional MR who have failed medical therapy (see section I.6).

F. Indications for intervention for secondary MR

1. The ACC/AHA guidelines do not provide any class I indications for surgery for secondary MR, because most studies have not shown a survival benefit of surgery in these patients despite symptomatic improvement.[199] Multiple studies comparing CABG with CABG + mitral valve repair for moderate ischemic MR have not shown any improvement in survival or LV reverse remodeling out to two years with either approach.[200–203] In the Cardiothoracic Surgical Trials Network Trial (CTSN) study comparing mitral valve repair and replacement for severe ischemic MR (which usually also included CABG), the two-year mortality was about 20% (19% after mitral valve repair and 23.2% after MVR),[204] and this comparable mortality between groups was confirmed in a meta-analysis.[205] Other studies of patients with HF from nonischemic severe MR with impaired LV function have shown that mitral valve repair may improve symptoms without any survival benefit compared with medical therapy.[206,207] Thus, the presence of secondary MR carries a poor prognosis whether surgery is performed or not.
2. Class IIa indications: stage C–D – mitral valve surgery is reasonable for chronic severe MR during CABG or AVR surgery. Most surgeons would certainly correct severe MR during such operations, as it will predictably improve symptoms. However, despite a reduction in late MR, no survival benefit to performing a mitral valve procedure for moderate or severe MR has been demonstrated in such cases.
3. Class IIb indications
   - Stage D – mitral valve surgery may be considered for patients with severe MR and persistent class III–IV HF symptoms on guideline-directed medical therapy (GMDT). In these patients, mitral valve repair and replacements have comparable long-term survival rates, but the risk of recurrence is significantly higher with mitral valve repair.[204,208] In the CTSN trial, the two-year recurrence rate of MR was 58.8% for repairs vs. 3.8% for replacement. Therefore, a chordal-sparing MVR has been suggested.

- Stage B – mitral valve repair may be considered for patients with moderate MR undergoing CABG. This may result in a lower risk of moderate MR at follow-up, but the rate of adverse events was similar to CABG alone with comparable two-year survival.

4. Unassigned indication – percutaneous mitral valve repair with a MitraClip (Abbott) was approved for patients with functional MR in 2019 in the United States. Only one of the two supporting trials showed a survival benefit, which was evident in patients with more severe MR but less advanced LV dysfunction.[209,210] Therefore, it was concluded that a MitraClip could reduce HF readmissions and mortality if applied to patients with persistent NYHA class II–IV symptoms on GDMT with ≥3+ MR (EROA ≥30 mm^2 and/or RV ≥45 mL) with an LVEF of 20–50% and LVESD <70 mm.[211]

G. Other comments

1. Atrial fibrillation (AF) is very common in patients with mitral valve disease, and persistence of AF after mitral valve surgery alone is more likely when LA size exceeds 5.5–6 cm or AF has been present over six months.[106] Postoperative AF is associated with reduced survival, worse late cardiac function, and less freedom from late stroke in patients with nonischemic MR and should be addressed by a Maze procedure with obliteration of the left atrial appendage at the time of mitral valve surgery.[187,188,212,213] It should also be considered in patients with AF and ischemic MR, primarily to reduce the risk of stroke. Reducing the size of a dilated left atrium may improve atrial mechanical function and improve the results of a Maze procedure.[214] A report from the Mayo Clinic found that there was a greater risk of developing late AF after mitral valve repair in patients with a left atrial size >50 mm or more than mild TR, although repairing the TR did not influence the risk of AF. This led to a proposal to perform a Maze procedure in these patients even in the absence of preexisting AF.[215]
2. In patients undergoing AVR who have moderate functional MR, the severity of MR improves in about 70% of patients following the AVR, with comparable survival to those in whom mitral valve repair is performed. The likelihood of improvement is greater in patients with a small left atrium, preoperative HF, lesser degrees of TR or MR, a lower ejection fraction and larger LV size, the presence of AR, and lower RV systolic pressures.[216–218] If degenerative MR is present with single-leaflet prolapse and eccentric jets, it is unlikely that the MR will improve after relief of the outflow tract obstruction, and consideration should be given to repairing 2–3+ MR.

H. Preoperative considerations

1. Patients with acute MR are susceptible to pulmonary edema and multisystem organ failure from reduced forward cardiac output. Use of inotropes, vasodilators, and often an IABP can transiently improve myocardial function and forward flow in anticipation of urgent cardiac catheterization and surgery. Intubation and mechanical ventilation are frequently required for progressive hypoxia or hypercarbia. Diuretics must be used judiciously to improve pulmonary edema while not creating prerenal azotemia. Some patients with chordal rupture who present with acute pulmonary edema may stabilize and develop chronic MR, which can be treated electively.

2. Patients with chronic MR are managed with diuretics or aldosterone antagonists (spironolactone, eplerenone) to reduce preload, and with vasodilators, such as the ACE inhibitors and ARBs, to improve forward flow. However, ACE inhibitors are usually beneficial only if the patient is symptomatic and has hypertension or systolic dysfunction. ACE inhibitors should not be given the morning of surgery, because of concerns about perioperative hypotension associated with their use.
3. Adequate preload must be maintained to ensure forward output while carefully monitoring the patient for evidence of HF. Systemic hypertension should be avoided because it will increase the amount of regurgitant flow. If the patient has ischemic MR or a borderline cardiac output, use of systemic vasodilators or an IABP generally improves forward flow.

I. Surgical procedures

1. Mitral valve reconstruction is applicable to more than 90% of patients with degenerative MR, although success rates are greater for posterior than anterior leaflet repairs. Techniques include annuloplasty rings, leaflet repairs, neochords, and chordal transfers (Figures 1.16 and 1.17).[107,219,220] Some of these reparative

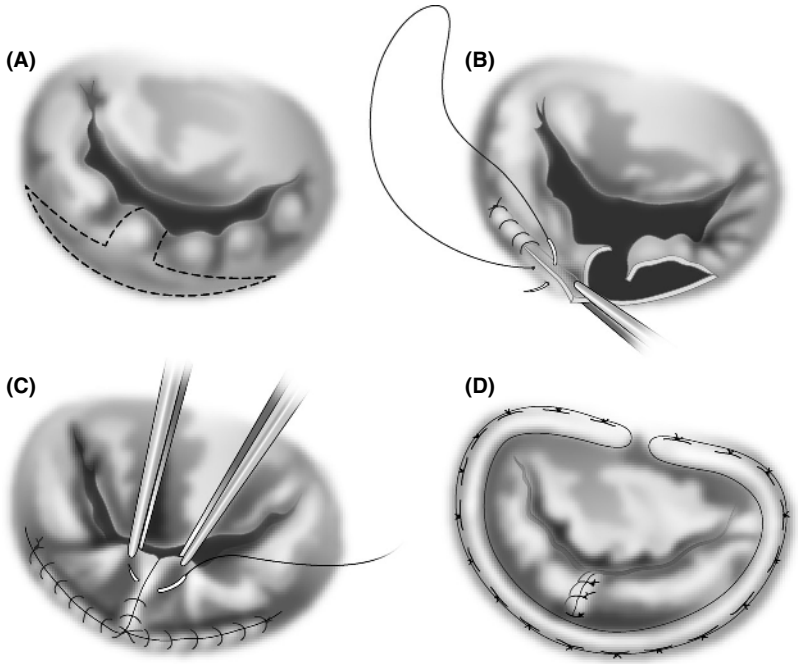


Figure 1.16 • Mitral valve repair. The most common pathology involves a flail posterior mitral leaflet. (A) A quadrangular excision is made as indicated by the dotted lines and the flail segment is resected. The remaining leaflet tissue may be incised along the annulus. (B) It is then advanced and reattached to the annulus ("sliding plasty"). (C) The leaflet tissue is then approximated, and (D) an annuloplasty ring is placed.

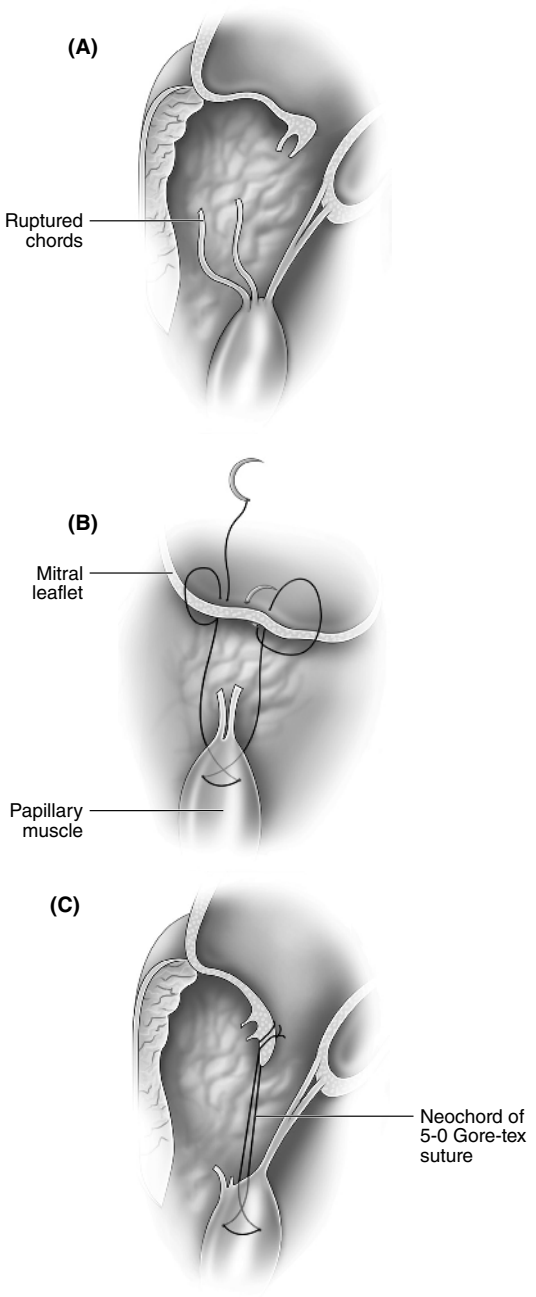


Figure 1.17 • Mitral valve repair with creation of PTFE neochords, used primarily for anterior leaflet prolapse. (A) Torn chords to one leaflet. (B) A figure-of-eight suture is placed through the head of the papillary muscle and each end of the suture is passed twice around the free edge of the leaflet. The suture is tied down to approximate the length of a normal length chord. (C) The final result after the suture is tied. (Image courtesy of Kaiser et al. *Mastery of Cardiothoracic Surgery*, Lippincott Williams and Wilkins 1st and 2nd editions.)

techniques can also be applied to patients with mitral valve endocarditis.[221,222] Mitral valve repair gives a survival advantage over mitral valve replacement (MVR) in patients with degenerative MR and coexisting CAD, but replacement appears superior for ischemic MR because of a lower recurrence rate despite equivalent survival.[204,208]

2. MVR is indicated when satisfactory repair cannot be accomplished. Acute MR from papillary muscle rupture usually requires MVR. Patients with ischemic MR have comparable clinical results and survival with MVR and repair, but a significantly lower rate of recurrence at two years with MVR. Chordal preservation of at least the posterior leaflet should be considered for all MVRs performed for MR. This improves ventricular function and will minimize the risk of LV rupture.
3. Traditional mitral valve operations have been performed through a median sternotomy incision, but other "minimal access" approaches have also been utilized successfully. An upper or lower sternotomy incision can be used and a right anterolateral thoracotomy or robotic approach through the right chest provide excellent visualization of the mitral valve. With experience, these procedures have comparable success rates of mitral valve repair and are associated with less blood loss, a lower rate of AF, and better cosmesis.[223–226] The latter two approaches do require femoral cannulation for bypass with its inherent complications.
4. A concomitant Maze procedure should be performed in patients with either paroxysmal or persistent AF. Whether a biatrial Maze procedure is superior to a left atrial Maze for these patients is controversial.[188,213,227]
5. The presence of TR or a dilated tricuspid annulus may affect long-term outcome and should be addressed at the time of mitral valve repair or replacement (see page 57).
6. Percutaneous approaches to MR continue to evolve and appear to be applicable to patients with both degenerative and functional MR.[211,228] The MitraClip mimics the "Alfieri stitch" in grasping both leaflets with a nitinol clip producing edge-to-edge approximation (Figure 1.18). Transapical off-pump mitral valve repairs with neochords have also been used succesfully.[229,230]
   a. The EVEREST II trial comparing MitraClip to surgical repair for degenerative MR found that the MitraClip was successful in reducing the degree of MR and improving clinical symptoms in high-risk patients, although the degree of MR reduction was inferior to that achieved with surgery. However, after a 30% conversion rate to surgery, most of which occurred during the first year, the MitraClip repair appeared durable. Owing to the high-risk population, the five-year mortality was comparable at about 20–25%.[198]
   b. As part of the Everest II trial, patients with functional MR underwent MitraClip placement. This was successful in reducing the degree of MR, reducing LV dimensions, improving symptoms, and reducing HF hospitalizations. The one-year survival for high-risk patients was only 74%, but was 86.4% for non-high-risk patients.[198]
   c. Subsequent studies have shown controversial benefits using the MitraClip device for functional MR. Data from the COAPT trial in 2018 showed that

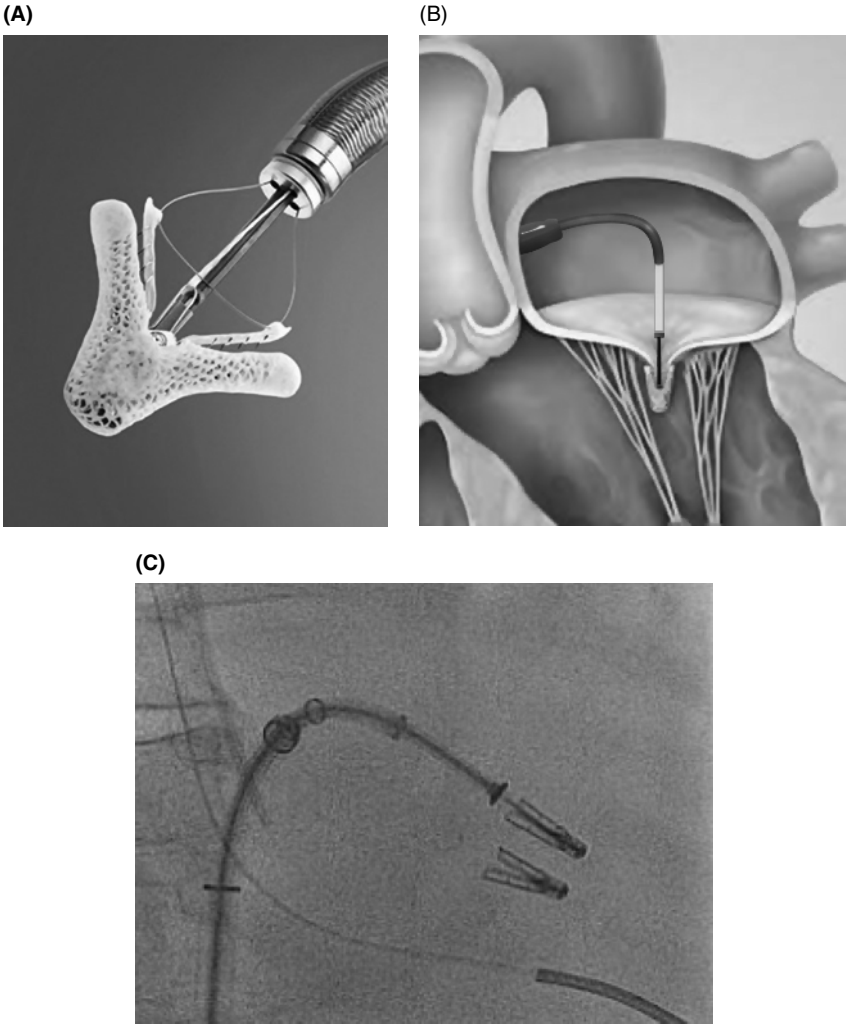


Figure 1.18 • (A) The MitraClip device. (B) The system passes transeptally into the left atrium and the clip is deployed, grasping both leaflets. (C) Fluoroscopic image demonstrating one deployed clip and the clip delivery system positioning a second clip lateral to the initial clip. (Image (B) courtesy of Mitraclip.com.)

percutaneous repair of severe secondary or functional MR in patients who remained symptomatic on optimal medical therapy had a lower rate of hospitalization and death at two years, although the combined endpoint was still quite significant (46% vs. 68%).[209] However, the Mitra-FR study published at the same time failed to show any difference in one-year survival comparing these two modalities, although the patients were not quite as ill as in the COAPT trial, yet had advanced disease with higher LVESVs.[210] The conclusion

of the COAPT trial was that MitraClip could be recommended only after patients had truly failed a course of optimal medical therapy and cardiac resynchronization therapy (CRT) if appropriate. The appropriate candidates had an LVEF of 20–50% and LVESD <70 mm.[211]

d. These studies confirmed the dismal prognosis of patients with secondary MR and LV dysfunction with one-year mortality rates of 22–24% (with/without intervention in the Mitra-FR study) and two-year mortality rates of 29% and 46% with and without interventions (COAPT).

VIII. Tricuspid Valve Disease

A. Pathophysiology[106]

1. Tricuspid stenosis (TS) is very rare, usually developing as a result of rheumatic heart disease in association with MS. It is invariably associated with the presence of TR.

2. TR is "functional" about 80% of the time, usually occurring as a consequence of left-sided heart disease which leads to PH and then pressure and volume overload of the RV. It may result from PH of any etiology. These conditions cause RV dilatation and remodeling with the subsequent development of tricuspid annular dilatation and leaflet tethering. Other common causes of TR include endocarditis (usually with IV drug abuse or hemodialysis) or valve distortion and damage from transvenous pacemaker leads.[231] RV systolic dysfunction leads to further elevation in right atrial (RA) and systemic venous pressures, producing signs of right-sided HF. Forward output may be reduced, resulting in fatigue and a low output state. AF is common.

B. Diagnosis

1. Tricuspid stenosis. Signs of systemic venous congestion are present (jugular venous distention, ascites, hepatomegaly, peripheral edema) with abnormal liver function tests from hepatic congestion. Echocardiography of severe TS will show a pressure half-time $\geq$190 ms with a valve area of $\leq$1 cm^2 and the right atrium and inferior vena cava (IVC) will be dilated. The presence of associated TR will further increase the diastolic gradient across the valve and increase the RA pressure.

2. TR produces a systolic murmur that increases with inspiration, prominent jugular venous pulsations, and, occasionally, a pulsatile liver. The diagnosis is confirmed by echocardiography, which can assess the tricuspid valve anatomy, the severity of TR, RV size and function, provide estimates of PA and RV pressures, and identify associated contributing pathology (Table 1.10).

C. Indications for surgery[107]

1. Tricuspid stenosis (TS)

a. Class I

- Tricuspid valve (TV) surgery is recommended for severe TS at the time of operation for left-sided valve disease. TV replacement (TVR) is recommended for patients at low surgical risk, especially if TR is moderate to severe.
- TV surgery is recommended for symptomatic, isolated severe TS. These patients may have class III–IV symptoms, including hepatic congestion, ascites, and peripheral edema, that are refractory to salt restriction and diuretics. TVR is usually performed.

Table 1.10 • Stages of Functional Tricuspid Regurgitation

Stage A: At risk of TR
Stage B: Progressive TR: echo findings of mild–moderate TR (see Table 1.11)
Stage C: Asymptomatic severe TR: echo findings of severe TR (see Table 1.11)
Stage D: Symptomatic severe TR: same as stage C but with fatigue, palpitations, dyspnea, abdominal bloating, anorexia, peripheral edema

Adapted with permission from Nishimura et al., *Circulation* 2014;129:e521–643.[107]

Table 1.11 • Echocardiographic Findings in Functional TR

	Mild	Moderate	Severe
Central jet area	<5 cm^2	5–10 cm^2	>10 cm^2
CW jet density	soft/parabolic	dense, variable contour	dense, triangular with early peak
Vena contracta width	not defined	<0.7 cm	>0.7 cm
Hepatic vein flow	mostly systolic	systolic blunting	systolic reversal
TV annular dilatation	early	early	>40 mm or >21 mm/m^2
RA/RV/IVC size	normal	normal to mildly enlarged	dilated with decreased IVC respirophasic variation
RA pressure	normal	normal	elevated
RV function	normal	normal	reduced in late phase
Leaflet tethering	mild	moderate	marked
Other			diastolic interventricular septal flattening

Adapted with permission from Nishimura et al., *Circulation* 2014;129:e521–643.[107]

b. Class IIb. Percutaneous balloon tricuspid commissurotomy might be considered in patients with isolated, symptomatic severe TS without accompanying TR who are at high surgical risk.

2. Tricuspid regurgitation[232]

a. Class I: Stage C–D: TV surgery is recommended when severe TR is present with mitral valve disease requiring mitral valve surgery. This must be undertaken after careful deliberation if severe RV dysfunction is present.

b. Class IIa
- Stage B – TV repair is beneficial for patients with mild, moderate, or greater functional TR at the time of left-sided valve-surgery when tricuspid annular dilatation (>40 mm or >21 mm/m^2) is present or there is prior evidence of right HF. Failure to reduce annular dilatation may subsequently lead to RV dysfunction, which will adversely affect functional outcome.
- Stage D – TV surgery can be beneficial for patients with symptoms due to primary TR that are unresponsive to medical therapy.

c. Class IIb
- Stage B – TV repair may be considered for moderate functional TR with pulmonary artery hypertension at the time of left-sided valve surgery.
- Stage C – TV surgery may be considered for asymptomatic or minimally symptomatic patients with severe primary TR and progressive TV dilatation and/or systolic dysfunction. However, operative risk is high when there is evidence of RV systolic dysfunction prior to TV repair.
- Reoperation may be considered for symptomatic patients with isolated TR following prior left-sided valve surgery in the absence of significant PH or significant RV systolic dysfunction, since the latter two conditions significantly increase the operative risk.

d. Persistent sepsis in a patient with TV endocarditis (see pages 63–64).

3. Comments on management of TR: the adverse effects of the dilated annulus and degree of TR.

a. Severe TR has a very poor prognosis if untreated, with a 64% one-year survival, and therefore should always be addressed during left-sided heart procedures.[233] Concomitant mitral valve repair should theoretically reduce pulmonary artery pressures, RV dilatation, and the degree of TR. However, the reduction in TR is unpredictable because the dilated annulus will usually not return to its normal size and configuration despite relief of elevated RV afterload. Severe preop TR may increase operative mortality rates, but severe late postop TR reduces long-term survival. Thus, a competent, long-lasting repair is important in these patients.

b. Moderate TR also reduces patient survival, estimated at 79% at one year.[233] Since improvement in TR after left-sided repair is unpredictable, TV repair should also be considered in these patients to prevent the progression of TR and the development of RV dysfunction and HF symptoms.[234–236]

c. Numerous risk factors for the persistence or progression of TR after left-sided valve surgery have been identified, several of which can be addressed by TV repair.[107] These include tricuspid annular dilatation (>40 mm or >21 mm/m^2 on echo or >70 mm measured intraoperatively), RV dysfunction, leaflet tethering height (the distance between the leaflet coaptation point and the annular plane in midsystole) >5 mm, PH, AF, and presence of an endovascular lead across the TV valve.[237]

d. Studies have shown that a dilated annulus is a predictor of progressive TR, and TV repair for a dilated annulus, irrespective of the degree of TR, is associated with less subsequent progression in the degree of TR, improved RV remodeling, and better functional outcomes, although survival may not be improved.[238–240]

One study found that a dilated annulus, even in patients with mild or no TR, may lead to worsening of TR if not repaired, although functional outcomes or survival may not be affected by performing the repair.[241] Although RV systolic function tends to be worse with severe TR, one study suggested that RV dysfunction, but not significant TR, was the reason for compromised long-term survival.[242]

D. Preoperative considerations

1. Passive congestion of the liver resulting from elevated right-heart pressures frequently leads to coagulation abnormalities, which should be treated aggressively before and during surgery. Frequently, these patients have uncorrectable INRs before surgery.
2. Salt restriction and diuretics may improve hepatic function, but significant improvement in liver function tests may not be possible until after surgery.
3. Maintenance of an elevated central venous pressure is essential to achieve satisfactory forward flow. A normal sinus mechanism provides better hemodynamics than AF, although the latter is frequently present. Slower heart rates are preferable for TS, and faster heart rates for TR.

E. Operative procedures

1. Tricuspid commissurotomy (balloon or under direct vision) can be performed for rheumatic TS.
2. Tricuspid annuloplasty with a ring (Carpentier) or suture technique (De Vega) should reduce annular dilatation and restore annular geometry (Figure 1.19). An undersized annuloplasty ring (26–28 mm) has been recommended by some surgeons for functional TR.[243] Ring annuloplasties appear to produce superior outcomes with less recurrence, but some studies have still noted a fairly high recurrence rate with rings (about 16%) at five years.[244–247] If the patient has severe TV tethering (tethering distance >0.76 mm or a tethering area >1.63 cm), adjunctive techniques may be necessary to achieve a satisfactory result from repair.[248]
3. A variety of techniques have been used to repair the tricuspid valve. Because most dilatation occurs at the posterior annulus, bicuspidization involving a mattress suture extending from the anteroposterior to the posteroseptal commissure along the posterior annulus can correct most cases of functional TR (Figure 1.20).[249] This technique can also be used when there is destruction of either the posterior or septal leaflet by endocarditis and can avoid TVR in many cases.[250,251]
4. Tricuspid valve replacement (TVR) is necessary when leaflet shrinkage and poor coaptation prevent an annuloplasty technique from eliminating the TR. There is no particular preference for valve selection.[252,253] Tissue valves have a lower risk of thromboembolism than mechanical valves when placed in the right heart, and valve survival may be better due to lower stress on the valve leaflets. Tissue valves may also be preferable because long-term survival after TVR is somewhat limited, most likely because it is associated with RV dysfunction and with more advanced multivalvular disease. The overall mortality rate for TVR whether performed as an isolated procedure or in combination with left heart surgery has been reported to be in the 20% range,[252–255] although reports from the STS database have indicated that it was around 9%.[256,257]
5. Percutaneous tricuspid valve repair has been accomplished using the MitraClip system.[258] Bicuspidizing the valve may reduce the degree of TR to some degree,

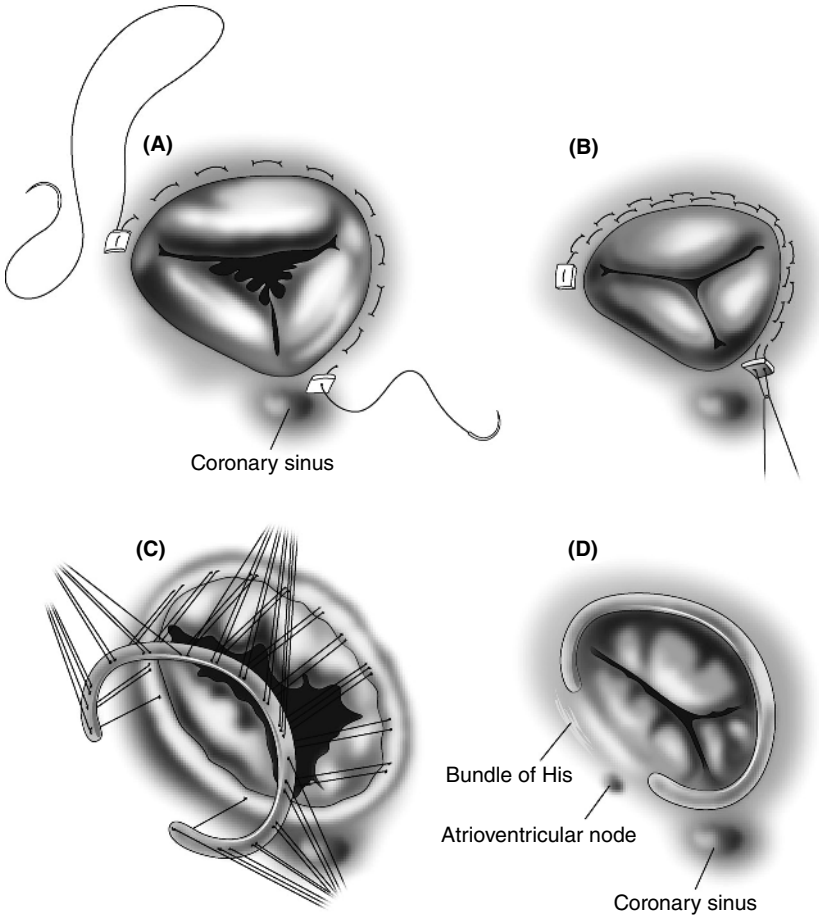


Figure 1.19 • Tricuspid valve repair involves reduction of annular dilatation to correct functional TR. (A, B) The circumferential suturing technique (De Vega repair). (C, D) Placement of an annuloplasty ring. Note the location of the coronary sinus and the proximity of the conduction system to the repair.

but this fails to reduce annular dilatation. Other devices are being investigated to improve leaflet coaptation and provide annular remodeling.[259,260]

6. Owing to the necessity of placing sutures near the conduction system, patients are more prone to developing heart block after tricuspid valve surgery. If there are concerns that permanent pacing may be required, epicardial pacing leads should be placed on the RV, pacing and sensing thresholds determined, and the pacing leads buried in a subcutaneous pocket for later attachment to a permanent pacemaker. In one report, more than 20% of patients undergoing TV surgery required postoperative permanent pacemakers.[261]
7. The management of tricuspid valve endocarditis is noted in the next section.

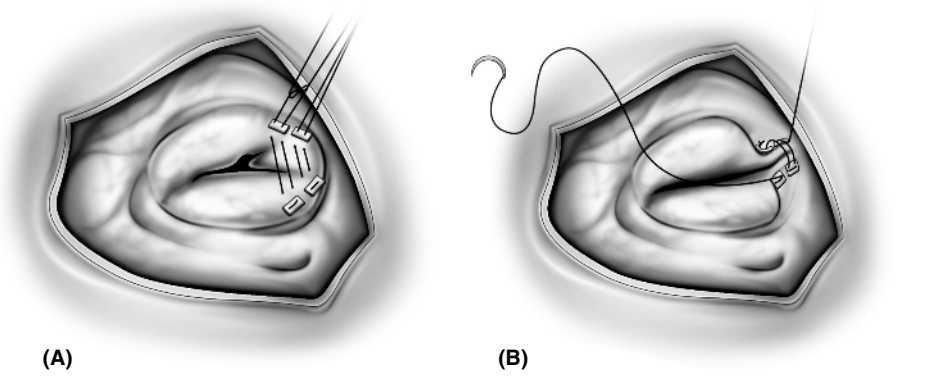


Figure 1.20 • Bicuspidization of the tricuspid valve for functional TR. (A) Two pledgeted mattress sutures are placed from the anteroposterior commissure to the posteroseptal commissure along the posterior annulus. (B) Tying down the sutures produces a "bicuspid" valve and should eliminate the TR.

IX. Infective Endocarditis

A. Pathophysiology. Infective endocarditis (IE) can result in the destruction of valve leaflets, invasion of surrounding myocardial tissue, systemic embolization of valve vegetations, or persistent systemic sepsis. Embolization is more likely with mitral than aortic valve involvement, staphylococcal organisms, and large (>10–15 mm) or mobile vegetations. Native valve endocarditis (NVE) is most commonly caused by *Streptococcus viridans*, *Staphylococcus aureus*, or coagulase-negative staphylococcal organisms. Tricuspid valve endocarditis is usually caused by IV drug abuse, although only 25% of intravenous drug abusers (IVDAs) have isolated tricuspid valve involvement.[262,263] The incidence of prosthetic valve endocarditis (PVE) is approximately 0.5–1% per patient-year for most mechanical and tissue valves. It is most commonly caused by staphylococcal organisms.

B. Diagnosis

1. The modified Duke criteria are used to diagnose endocarditis.[106,107] These include two major criteria (positive blood culture and echocardiographic findings consistent with endocarditis) and several minor criteria (a predisposing condition, fever, vascular or immunologic manifestations).
2. Transthoracic echo (TTE) can usually identify vegetations, valve pathology, and anterior prosthetic valve abscesses, but its overall sensitivity for NVE is 50–90% with a specificity of 90%. Sensitivity is only 40–70% for PVE.[264]
3. Transesophageal echo (TEE) is usually more sensitive and specific in identifying complex problems, such as perforations, abscesses, and fistulas. It should be performed if the TTE is positive or nondiagnostic, if complications are present, and if surgery is to be performed (Figures 2.25 and 2.26).
4. When there are indeterminate findings on TTE or TEE, which is quite common with PVE or with pacemaker or defibrillator lead involvement, nuclear imaging studies, including metabolic imaging (^{18}FDG PET-CT scanning) and radiolabeled leukocyte scintigraphy using single-photon emission CT (SPECT) may be useful.[264–266]

5. Cardiac CT is helpful in identifying paravalvular complications and should be considered to rule out coronary pathology since it is important to avoid catheter manipulation in the aortic root when aortic valve endocarditis is present.[267]
6. Routine brain CT scanning is essential in patients sustaining a neurologic complication, especially to identify hemorrhage, which usually contraindicates early surgery. Brain MRI may detect subclinical cerebral complications, including embolism, abscesses, or hemorrhage, in upwards of 80% of patients,[264] although such findings may not influence decisions regarding early surgery. CT cerebral angiography has identified small intracranial mycotic aneurysms in more than 30% of patients as well.[264] This may account for the finding of small ectopic hemorrhagic strokes in many patients after surgery.[268]

C. **Indications for surgery in native and prosthetic valve endocarditis.** Although medical therapy is often successful in the treatment of IE, certain pathologic problems portend an ominous prognosis for which urgent surgery is indicated. These conditions are HF due to valvular regurgitation, cardiac invasion, and large vegetations with an increased risk of systemic embolization. ACC/AHA guidelines noted below do not differentiate between right- and left-sided endocarditis.[107] The European Society of Cardiology (ESC) guidelines do make that distinction, and also provide the recommended timing for surgery (Table 1.12)[269] Indications for early surgery before completion of a full course of antibiotics per the ACC/AHA guidelines are:

1. Class I indications
   a. Valve dysfunction causing symptoms of HF. Despite its high risk, surgery should not be delayed if cardiogenic shock or pulmonary edema is present unless the likelihood of recovery from complications (severe stroke) is remote. Otherwise, the patient will develop multisystem organ failure and likely die without surgical intervention.
   b. IE caused by *S. aureus*, fungal, or other highly resistant organisms. These are aggressive organisms that are associated with large vegetations, embolization, cardiac invasion, and persistent infection.
   c. Evidence of local extension resulting in heart block, aortic or annular abscesses, or destructive penetrating lesions (intracardiac fistulas, mitral leaflet perforation from aortic valve endocarditis). For prosthetic valves, this may produce valve dehiscence with a paravalvular leak or rocking on echo.
   d. Persistent infection manifested by persistent bacteremia or fevers after 5–7 days of appropriate antibiotic therapy.
   e. For PVE, a relapsing infection after completion of a course of antibiotics during which blood cultures are negative.
2. Class IIa: recurrent embolization with persistent vegetations despite antibiotic treatment. The risk of embolization is highest during the first week of antibiotic therapy and occurs in up to 50% of patients, then rapidly declines to very low levels after two weeks.[269–271] Thus, very early intervention can be recommended to avoid recurrent embolization. Embolization risk correlates with older age, diabetes, AF, previous embolization, vegetation length, and *S. aureus* infection.[272]
3. Class IIb: mobile vegetations >10 mm in diameter even in the absence of documented embolization. These vegetations, especially on the mitral valve and with *Staph*. organisms, have an increased risk of embolization. Early surgery has been shown to reduce embolic events and improve survival.[273,274]

Table 1.12 • Indications for Surgery for Left-Sided Valve Infections per the European Society of Cardiology

Class	Timing	
Heart Failure		
I	Emergent	NVE or PVE with severe AR or MR, obstruction, or fistula causing refractory pulmonary edema or cardiogenic shock
I	Urgent	NVE or PVE with severe AR or MR or obstruction with symptoms of CHF or echo signs of poor hemodynamic tolerance causing heart failure symptoms (high LVEDP, PH, high LA pressures)
Uncontrolled Infection		
I	Urgent	Locally uncontrolled infection (abscess, false aneurysm, fistula, enlarging vegetation) – i.e. persistent positive blood cultures after 7–10 days of antibiotics; perivalvular abscess is noted in 10–40% of aortic NVE and 56–100% of PVE
I	Urgent/elective	Infection with fungal or multiresistant organism
IIa	Urgent	Persistent positive blood culture on appropriate antibiotics and adequate control of septic metastatic foci
IIa	Urgent/elective	PVE with *Staph.* or HACEK gram-negative organism
Prevention of Embolism		
I	Urgent	Aortic or mitral NVE or PVE IE with persistent vegetations >10 mm after ≥1 embolic episode on antibiotics
IIa	Urgent	Aortic or mitral NVE with vegetations >10 mm with severe valve stenosis or regurgitation and low surgical risk
IIa	Urgent	Aortic or mitral NVE or PVE with very large vegetations >30 mm
IIb	Urgent	Aortic or mitral NVE or PVE with isolated vegetation >15 mm and no other indication for surgery

Adapted with permission from Habib et al., *Eur Heart J* 2015;36:3075–128.[269]

D. Specific issues

1. **Neurologic complications.** Approximately 15–30% of patients manifest overt neurologic complications from IE and another 35–60% may develop clinically silent cerebral embolization.[264,265,269] Concerns that early surgery will exacerbate a neurologic deficit due to heparinization and hypotension have not been substantiated, and urgent surgery is recommended to prevent recurrent embolization in the absence of cerebral hemorrhage on CT scan. If there is evidence of intracerebral bleeding, surgery should be delayed at least four weeks. However, micro-

bleeds noted on MRI scanning should not be considered equivalent to intracerebral hemorrhage and should not contraindicate urgent surgery.[269] Ectopic intracranial hemorrhage has been noted postoperatively in over 10% of patients regardless of the timing of surgery and may be related to mycotic angiopathy or small undetected mycotic aneurysms.[274] In most patients, the indication for surgery will be HF, uncontrolled infection, large mobile vegetations with high embolic risk and less commonly, a perivalvular abscess. Intracranial infectious aneurysms may be identified by CT or MR angiography prior to surgery.

2. **Tricuspid valve infective endocarditis** (TVIE) comprises 5–10% of all cases of IE and is usually noted in IVDAs, as well as patients with hemodialysis catheters and pacing/defibrillator leads.[275,276] *S. aureus* is the most common organism. These patients usually present with fever, bacteremia, and septic pulmonary emboli, and most eventually develop TR. Fortunately, IV antibiotics can successfully treat 70–85% of these patients, with a fairly low mortality. The threshold for recommending surgery is fairly high in IVDAs because of concerns about the influence of IV drug recidivism on recurrent endocarditis and survival.[262,276–281]
   a. A meta-analysis of patients with TVIE (41% with IVDA) found comparable four-year survivals with TV repair and TVR, but repair was associated with more residual moderate–severe TR, less recurrent IE, fewer reoperations, and a reduced need for a permanent pacemaker.[276]
   b. A study from the Cleveland Clinic of TVIE also found that a significant percentage of patients (44%) undergoing TV repair were left with moderate–severe TR, but this did not worsen with time, and TV repair produced significantly better survival out to seven years than TVR. Five-year survival was about the same for TVIE resulting from IVDA and cardiac implantable devices, but was only 18% in patients on dialysis.[278]
   c. Another study from the Cleveland Clinic of IE in IVDA patients, independent of valve location, reported a 10-fold increase in the risk of death or reoperation between three and six months after surgery, most likely due to recurrent IV drug abuse.[279]
   d. A study from Boston reported a nearly fourfold increase in valve-related complications in IVDAs, usually attributable to valve reinfection.[263] That study found no difference in 10-year survival between IVDA patients and non-IVDA patients (about 70% survival), but a 60% reinfection rate at eight years for IVDA. Other studies suggest that 10-year survival for IVDAs was much worse at 40%.[280]
   e. Early surgery for TVIE is indicated when the standard indications for concomitant left-sided endocarditis are present, and when there is an infected pacemaker lead or PVE. The association of left-sided endocarditis with TVIE compromises survival. However, a conservative approach has been recommended in IVDAs with isolated TVIE, such that persistent bacteremia but not recurrent septic pulmonary emboli should be the only strong indication for early surgery. However, in other patients with severe TR, early surgery might permit tricuspid repair before extensive destruction of tricuspid valve tissue has occurred since repair is highly protective against recurrent TV IE.[279] The Cleveland Clinic data support this concept of trying to repair the TV at all costs, but it is not clear if this approach and the results

achieved at this world-class institution are reproducible by less experienced surgeons. Indications for surgery may include:

- Worsening right HF from severe TR with poor response to diuretic therapy.
- Persistent vegetations >20 mm with bacteremia (and possibly recurrent septic pulmonary emboli).
- Difficult to eradicate organisms (fungus).
- Bacteremia for at least seven days despite adequate antibiotics (especially if *Staph*. or *Pseudomonas*).

3. **Cardiac implantable electronic device-related infective endocarditis (CDRIE)** from pacemakers and defibrillator implants can be difficult to identify but must be suspected in any patient with positive blood cultures. This is to be differentiated from local device infection which involves the device and implantation pocket without lead involvement. TEE is more sensitive than TTE in identifying lead-associated vegetations, but differentiation from clot or adherent tissue is not always possible. Use of intracardiac echocardiography (ICE), ^{18}FDG-PET/CT or radiolabeled leukocyte scintigraphy may be helpful.[269] Complete hardware removal, including the device and lead) is indicated when CDRIE is suspected.[264,269]
   a. Percutaneous transvenous lead extraction is preferable to avoid an open-heart procedure, but has moderate risk and requires expertise. Extraction may result in embolization of vegetations, but this is usually not clinically significant.
   b. Open extraction should be considered if percutaneous removal is unsuccessful or there is severe destructive TVIE or very large vegetations >20 mm.
   c. If the patient is pacer-dependent, temporary transvenous pacing leads may be necessary, but they are a risk factor for subsequent cardiac device infection. Use of active fixation leads connected to external devices produces secure leads until another permanent pacing system can be implanted.[282]
   d. When there is evidence of NVE or PVE and no evidence of CDRIE, it may be possible to leave the system behind, so the European guidelines assigned a level IIb indication to removing the device and leads.
4. **Hemodialysis** patients have a high risk of bloodborne infections and are more prone to NVE and PVE. Hospital mortality rates for patients on hemodialysis who present with endocarditis were 23.5 and 37% in two studies.[283,284] In fact, US national data showed that only 10–15% of these patients survived three years.[283] In surgical studies, operative mortality rate has been quite high (42% in one study of AVRs)[285] with recurrent PVE in 50% of patients by five years and an overall five-year survival of around 20%.[278,286,287] Thus, it is predictable that these patients will do very poorly even following appropriate guidelines.
5. **Transcatheter valve** infections occur at a rate of 1–2%/year (comparable to surgical valves), and tend to occur in the first six months following the procedure.[288,289] They are usually associated with other surgical procedures, chronic vascular access (hemodialysis), or peripheral vascular disease. There is limited experience in dealing with this complication, but the hospital mortality rate with medical management approaches 50%. Because many patients have undergone TAVR because of high surgical risk, an operative approach to remove the transcatheter valve may also carry high risk. With lower-risk patients now undergoing TAVR, this is

surely going to become a more common problem that will need to be managed with similar indications as for surgical prosthetic valve endocarditis, but may require more complex aortic root procedures.

E. Preoperative considerations

1. **Antibiotic therapy.** Ideally, the patient should receive a six-week course of antibiotics prior to surgery, which should reduce the risk of PVE from about 10% down to 2%. However, hemodynamic deterioration, intracardiac invasion, and risk of embolization are compelling indications for earlier surgery. Attempts should be made to optimize hemodynamic and renal status before operation in patients with hemodynamic compromise, but surgery should not be delayed if there is evidence of progressive organ system deterioration, especially with acute AR or MR. The appropriate antibiotics should be given for a total perioperative course of six weeks, although a shorter course may be feasible if complete extirpation of the infection is achieved and microbiology suggests very sensitive organisms such as *Streptococcus*.
2. Patients with aortic valve endocarditis may have evidence of heart block from involvement of the conduction system by periannular infection. This may require preoperative placement of a transvenous pacing wire.
3. Coronary angiography should be avoided, if possible, when mobile aortic valve vegetations are identified. Cardiac CT angiography can be performed to identify potential coronary stenoses.

F. Surgical procedures

1. Surgery entails excision of all infected valve tissue, drainage and debridement of abscess cavities, and repair or replacement of the damaged valves.[290] An aortic valve homograft is arguably the valve of choice for aortic valve IE because of its increased resistance to infection and adaptability to disrupted tissue in the aortic root.[160,291] However, homograft replacement is technically quite complex and the operative mortality may be greater when performed by surgeons without extensive experience with these conduits. AVR with either mechanical or tissue valves is a satisfactory alternative with a comparable rate of complications and late mortality to homografts in several studies.[292,293] The risk of PVE on tissue or mechanical valves is fairly comparable.
2. Mitral valve endocarditis can frequently be repaired, especially if leaflet perforation is the primary pathology, and there are proponents of earlier surgery in mitral valve endocarditis to preserve the patient's native valve.[294] More advanced stages of endocarditis usually require valve replacement.
3. Tricuspid valve endocarditis should usually be treated more conservatively, especially in IVDAs who remain at increased high risk of developing PVE.
   a. When surgery is indicated, tricuspid valve repair is usually recommended and should be attempted aggressively in these patients.[278–280] Bicuspidization after resection of infected tissue is often successful. Otherwise, the tricuspid valve should be replaced, accepting the higher risk of recurrence. Again, the Cleveland Clinic data recommended a TV repair even if it leaves the patient with a significant amount of TR, and the authors recommended avoiding a TVR if at all possible.[278]

b. Although most surgeons believe that a valvectomy should only be performed in extreme cases and in the absence of PH, a single center study comparing valvectomy with TVR and TV repair found similar 30-day mortality rates and a lower readmission rate at one year with valve excision than TVR (although 60% of patients were lost to follow-up).[295] The readmission rate after TVR was 23% and was usually associated with recurrent infection. Apparently, since many patients already have severe TR, they appear to tolerate valve excision well without developing severe HF. Generally, if TV repair cannot be successfully performed, TVR should be considered if the patient is undergoing left-sided valve surgery, has PH, and is not an IVDA. However, valvectomy may be a reasonable option if IVDA recidivism is highly likely and the valve cannot be repaired.

X. Hypertrophic Obstructive Cardiomyopathy

A. Pathophysiology. Hypertrophic obstructive cardiomyopathy (HOCM) is characterized by diastolic dysfunction and varying degrees of dynamic LVOT obstruction. The latter most commonly results from hypertrophy of the basal septum with mitral–septal apposition from systolic anterior motion (SAM) of the mitral valve. This also leads to MR from incomplete leaflet apposition. A variety of anomalies of the mitral valve and papillary muscles may contribute to these problems, including elongated anterior and posterior mitral leaflets (AML and PML), anterior and basilar displacement of the anterolateral papillary muscle, and the insertion of the anterolateral papillary muscle or anomalous chords into the middle of the AML.[296–300]

B. Clinical presentations. Several different clinical patterns may be noted with HOCM.

1. Patients generally become symptomatic with congestive HF, which is related to diastolic dysfunction, left ventricular outflow tract (LVOT) obstruction, and the presence of MR. About 70% of patients have either resting or provoked LVOT obstruction, with 25% having a significant resting gradient. LVOT obstruction with a gradient >30 mm Hg at rest or with exercise is an independent predictor of the development of HF and carries a poor prognosis. Syncope may occur due to hemodynamic compromise from LVOT obstruction.

2. Angina from microvascular ischemia may develop because of abnormal coronary microvasculature and inadequate capillary density for the degree of hypertrophy.

3. Supraventricular and ventricular arrhythmias are noted with HOCM, and the risk of sudden death is estimated at 0.5–1.5%/year, being more common in patients <age 30 and rare in patients >age 60. This risk is increased in patients with any of the following major risk factors:[300]

- History of cardiac arrest
- Family history of HOCM-related sudden death
- Sustained ventricular tachycardia (VT) or repetitive prolonged bursts of nonsustained VT
- Massive LVH >30 mm
- LV apical aneurysm
- Late gadolinium enhancement (LGE) >15% of LV mass
- End-stage HOCM with an EF <50% and an LV apical aneurysm

4. Advanced HF may develop with remodeling and systolic dysfunction that may require heart transplantation.
5. Atrial fibrillation (AF) may develop due to left atrial enlargement in 20% of patients and is not uncommon in patients with advanced HF and systolic dysfunction. Because of impaired LV filling due to the lack of atrial "kick" with severe LVH, cardiac output may be compromised. AF is generally poorly tolerated and is a predictor of adverse outcomes. Management may involve amiodarone for rhythm control, anticoagulation to minimize the risk of stroke, potential catheter ablation if the rhythm is not well-tolerated, and possibly a Maze procedure at the time of surgical myectomy.
6. Patients with nonobstructive hypertrophic cardiomyopathy generally have a benign course with only 10% progressing to class III/IV symptoms. Their survival is comparable to age-matched controls.[301]

C. Diagnosis

1. Echocardiography at rest and with exercise will demonstrate the anatomic variant of HOCM (most commonly upper septal hypertrophy), the resting outflow tract gradient, the provocable gradient, and the degree of MR and its mechanism (usually SAM). TEE is essential to identify abnormalities of the mitral valve leaflets and papillary muscles so that they can be addressed at the time of surgery.
2. During left heart catheterization, the Brockenbrough–Braunwald–Morrow sign may be noted. This occurs when a post-PVC beat results in a reduction rather than an increase in the arterial pulse pressure despite increasing diastolic filling time, increased LVEDP, and an increase in LV systolic pressure. The increase in cardiac stretch increases cardiac contractility and accentuates the outflow tract gradient, reducing the blood pressure.
3. Risk stratification for sudden death may be improved by use of contrast-enhanced CMR using gadolinium. The risk of sudden death is proportional to the degree of LGE, which reflect areas of myocardial fibrosis (Figure 2.40). Patients with absent LGE are at low risk for sudden death, whereas those with LGE >15% of LV mass are at higher risk, even in the absence of other risk factors. The extent of LGE correlates with adverse LV remodeling and the progression to end-stage HOCM with LV systolic dysfunction.[300,302,303]

D. Indications for intervention

1. No pharmacologic regimen has been shown conclusively to reduce the risk of sudden death. However, β-blockers decrease cardiac inotropy, are effective in blunting gradients provoked by exercise, and generally improve symptoms. They are recommended for patients with or without obstruction. Verapamil is a second alternative, and disopyramide can be added when there is significant outflow tract obstruction as it will decrease SAM and the outflow gradient.
2. Dual-chamber pacing and biventricular pacing might be useful in reducing the gradient, but these modalities are only indicated if a dual chamber implantable cardioverter-defibrillator (ICD) is implanted or if the patient is not a candidate for an ablative procedure.
3. Further intervention is indicated in patients with a gradient >50 mm Hg at rest or with provocation who have persistent symptoms despite medications or have syncope due to LVOT obstruction. Intervention may also be considered in asymptomatic patients considered at high risk for sudden death, including younger patients and those with a peak gradient >80 mm Hg.

E. Preoperative considerations

1. Measures that produce hypovolemia or vasodilatation must be avoided because they increase the outflow tract gradient. Volume infusions should be used to maintain preload with the use of a-agonists to maintain systemic resistance.
2. Use of β-blockers and calcium channel blockers to reduce heart rate and contractility are the mainstay of the medical management of HOCM and should be continued up to the time of surgery.

F. Interventional procedures[304]

1. The traditional surgical approach of a LV septal myectomy entailed resection of a 1.5 × 4 cm wedge of septum below the right coronary aortic leaflet through an aortotomy incision.
2. With further understanding of the mechanism of SAM, the current operation is more elaborate and involves performing an extended septal myectomy to the base of the papillary muscles, mobilization and partial excision of the papillary muscles off the ventricular wall to allow the papillary muscles to assume a more posterior position in the LV, and AML plication if there is any redundancy. This reduces chordal and leaflet slack that can produce SAM (Figure 1.21). Surgery can successfully treat patients with massive LVH and other subvalvular issues that contribute to LVOT obstruction or MR that cannot be addressed by alcohol septal ablation.

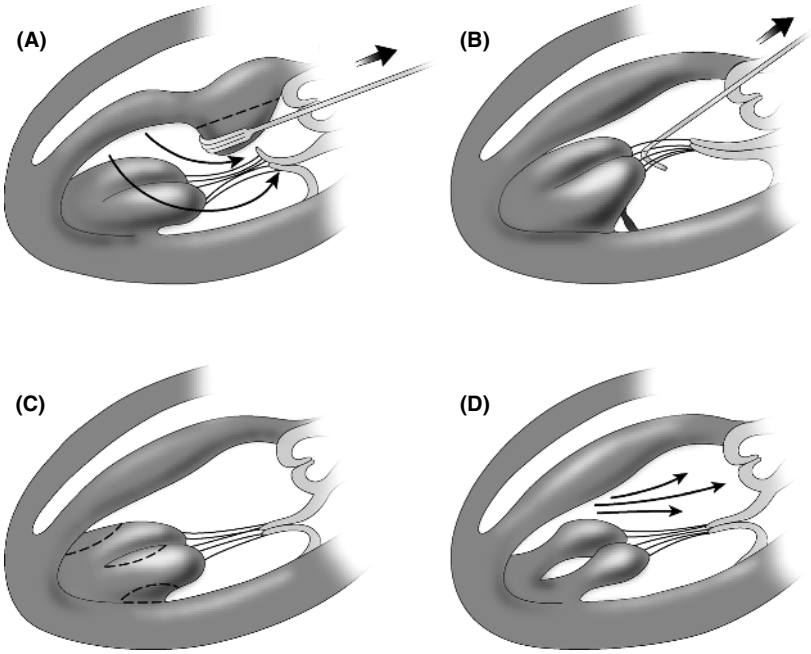


Figure 1.21 • (A) Hypertrophic obstructive cardiomyopathy is characterized by septal hypertrophy, which orients the outflow jet into the anterior leaflet of the mitral valve, producing SAM. An extensive septal myectomy is performed, often requiring a midventricular resection. (B, C) Using a nerve hook to provide traction, the atypical attachments of hypertrophied anomalous papillary muscles are partially detached from the ventricular wall and trimmed. (D) After this procedure, the outflow jet is directed more anteriorly.

a. The concept of "resect-plicate-release" should be applied depending on the degree of septal thickness (resect if >18 mm), AML height (plicate AML if >30 mm or >17 mm/m^2), and anterior displacement of the anterolateral papillary muscle (release/resection of the papillary muscle by extending the resection laterally into the free wall above the base of the papillary muscle). Resection of midventricular obstruction or anomalous chords and relief of papillary muscle fusion may be necessary.[296]

b. A successful operation dramatically reduces the gradient, eliminates MR, improves functional status, and may reduce the risk of sudden death. This procedure is also successful in reducing the gradient in patients with significant LVOT obstruction or MR but less basal septal hypertrophy by "plication" and "release" without septal resection.

c. A comprehensive extended myectomy and subvalvular procedure should eliminate SAM and MR in patients without intrinsic mitral valve disease or elongated chords.[305] Only if these problems are present should an MVR be necessary.[306]

3. Alcohol septal ablation of the upper septal perforator branch of the LAD produces an infarct of the upper septum. This should reduce basal septal thickness (which may take up to three months), which enlarges the LV outflow tract and reduces SAM in appropriately selected patients. It has been shown to produce a substantial reduction in gradient with improvement in symptoms, exercise tolerance, and possibly survival.[307]

a. Although comparative studies suggest that septal myectomy produces a lower gradient and reduces the need for permanent pacemaker implantation (3% vs.10%) than alcohol septal ablation, no significant difference in long-term survival, functional class, or ventricular arrhythmias has been noted, except perhaps better symptom relief in patients <age 65.[307]

b. Nonetheless, because open-heart surgery allows the surgeon to address papillary muscle pathology, massive LVH, and perform a concomitant cardiac procedure (for coronary disease or AF) and because it avoids the long-term concerns of creating an arrhythmogenic focus with alcohol ablation, myectomy is the preferred procedure, reserving alcohol septal ablation for older patients and those considered high risk for surgery.

4. Transcatheter mitral valve repair using the MitraClip device has seen limited use in HOCM, but may be considered in patients with severe MR and systolic anterior motion who are at prohibitive risk for surgical myectomy or have coronary anatomy not amenable to alcohol septal ablation. It can reduce the LVOT gradient and the degree of MR.[308]

5. ICD placement should be considered in patients at high risk for sudden death (as noted above) and has been the only modality demonstrated to reduce that risk and prolong life.

XI. Aortic Dissections

A. **Pathophysiology.** An aortic dissection results from an intimal tear that allows passage of blood into the media, creating a false channel. This channel is contained externally by the outer medial and adventitial layers of the aorta. With each cardiac contraction, the dissected channel can extend proximally or distally, potentially causing branch artery compromise or rupture as the outer wall weakens. Dissections involving the

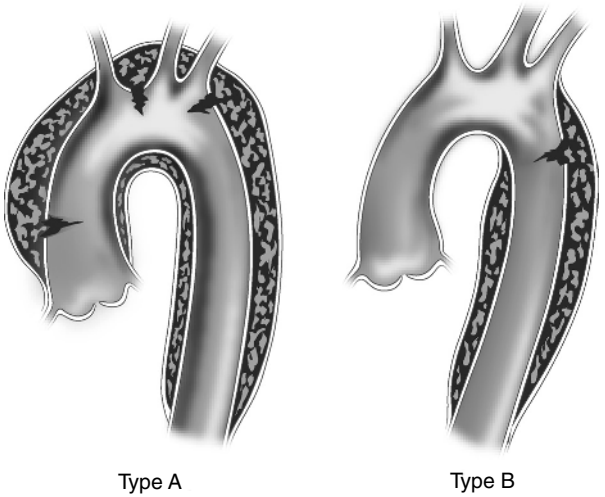


Figure 1.22 • Classification of aortic dissection. Type A dissections involve the ascending aorta. Type B dissections usually originate distal to the left subclavian artery and do not involve the ascending aorta. If they do extend retrograde, they are then considered type A dissections.

ascending aorta are classified as Stanford type A (DeBakey type I–II, or proximal) dissections, whereas those not involving the ascending aorta are called Stanford type B (DeBakey type III, or distal) dissections (Figure 1.22). In the past, a dissection was termed "acute" when diagnosed within two weeks of its onset; otherwise, it was termed "chronic". The International Registry of Acute Aortic Dissections (IRAD) has reclassified dissections as the following: hyperacute (<24 hours from symptom onset), acute (2–7 days), subacute (8–30 days) and chronic (>30 days) from symptom onset.[309] Either cystic medial degeneration or increased aortic wall stress (usually hypertension) is present in most patients with aortic dissection.[310,311] A variant of an acute dissection is an intramural hematoma in the absence of an intimal tear, which is usually treated in the same manner.

B. Presentation

1. **Type A dissection.** This is a life-threatening condition that must be considered in any patient presenting to the emergency room with the acute onset of chest pain. Failure to be aware of the various presentations of type A dissections has led to a misdiagnosis in up to 40% of patients.[312] Early suspicion and evaluation are critical to expedite surgery since the estimated mortality rate for medically managed type A dissections is about 15–30% during the first 24 hours (about 1–2%/h), then 10–20% in the next 24 hours, before decreasing.[313]
   a. The traditional notion is that patients develop tearing, ripping chest pain that radiates to the back, and have severe hypertension, a widened mediastinum on chest *x*-ray, and a normal ECG on admission. However, IRAD data have reported this classic presentation to be uncommon. In an IRAD report from 2015 that looked at trends in demographic data, the most recent three-year interval found tearing, ripping chest pain to be present in only 23.8% of patients, hypertension on admission in 27%, a widened mediastinum in 52.2%

with a normal chest x-ray in 28.6%, and a normal ECG in 40.7%.[314] The key symptoms that had not changed over time were the presence of **the acute onset of severe pain**, whether neck, chest, back, or abdominal, which is usually the worst pain the patient has ever experienced. The pain is caused by tearing of the aortic wall and its extension; it often abates and may wax and wane – this may be deceptive to the clinician if this fact is not appreciated.

b. An "aortic dissection risk score" (ADD) based on IRAD data was published in 2011 and is very helpful in prioritizing the work-up of patients presenting with chest pain.[315] This assessed three clinical categories and assigned one point to each. In this study, nearly 96% of patients with dissections had an ADD score of 1–3. It was recommended that expedited imaging be performed for scores of 2–3 and for an ADD score of 1 if there was no specific alternative diagnosis. Expedited imaging was also recommended for an ADD score of 0 in patients with unexplained hypotension or a widened mediastinum. Even if these findings were not present, aortic imaging should still be considered in patients presenting with syncope or with other risk factors for dissection (for example hypertension) if no clear alternative diagnosis is present.

- **i.** High-risk conditions – Marfan syndrome, family history of aortic disease, known aortic valve disease or thoracic aneurysm, or prior aortic manipulation.
- **ii.** High-risk pain features – chest, back, or abdominal pain that is abrupt in onset, severe in intensity, or ripping, tearing. It should be noted that the original publication states that any of these features had to be present, not all three.
- **iii.** High-risk exam features – pulse deficit, blood pressure differential, focal neurologic deficit in conjunction with pain, murmur of AR, hypotension or shock.

c. Depending on the location of the intimal tear and the extent of the dissection, potential complications include cardiac tamponade from hemopericardium (the most common cause of death), AR, MI, stroke, and branch artery compromise causing malperfusion. The latter may involve the brachiocephalic vessels, causing syncope, a stroke, or a discrepancy in upper-extremity blood pressures; the intercostal vessels perfusing the spinal cord, causing paraplegia; the mesenteric or renal vessels, compromising blood flow to the bowel or the kidneys; or the iliofemoral vessels, reducing distal blood flow to the legs. Surgical mortality rates increase approximately 10% for each organ system involved with malperfusion.[316]

d. An elevation in D-dimer levels is usually, but not always, noted in acute dissections and may be useful in supporting suspicion of the diagnosis.[317,318] However, an ADD of 0 combined with a negative D-dimer essentially rules out the presence of an aortic dissection.[319] Another biomarker that is being studied is smooth muscle myosin heavy chain protein that is released from damaged aortic medial smooth muscle.

2. Type B dissection. This classically presents with back pain that may radiate into the abdomen. However, IRAD data reported that 78% of patients with type B dissections presented with anterior chest pain, so pain location does not reliably correlate with the site of the dissection.[314] Potential rupture into the mediastinum, pleural spaces, or abdomen may occur. Malperfusion from branch artery compromise from the descending thoracic and abdominal aorta may occur as noted above.

C. Indications for surgery

1. **Type A dissection.** Surgery is indicated for all patients unless it is considered to carry a prohibitive risk because of patient age, overall medical condition and comorbidities, or the development of extensive renal, myocardial, or bowel infarction or massive stroke. In selected cases of mesenteric malperfusion, fenestration, and/or stenting may be indicated prior to surgical repair of the site of the dissection.[320,321] Surgery is also indicated for virtually all patients with chronic type A dissections.
2. **Type B dissections.** Patients with uncomplicated type B dissections are usually treated medically with mortality rates of 2–6%.[322–325] Interventional (endovascular) or surgical procedures have traditionally been reserved for patients with complicated dissections. This has been defined as persistent pain, uncontrollable hypertension, evidence of aneurysmal expansion or rupture, or visceral, renal, or lower-extremity vascular compromise. However, the long-term prognosis of medically treated type B dissections is not ideal, with a 30–40% likelihood of developing subsequent aneurysmal expansion or a complicated dissection. This is more likely if the patient's heart rate and blood pressure are not well controlled, the false lumen remains patent, the initial aortic diameter is >40 mm, the false lumen diameter is >22 mm, or the proximal entry tear is >10 mm.[325] Because of this concern, it has been proposed that patients with uncomplicated dissections but high-risk features for increased growth rate should undergo elective endovascular procedures to optimize their survival. Chronic type B dissections should be operated upon when they reach 6 cm in diameter.

D. Preoperative considerations and diagnostic testing

1. **Medical management**
   a. Upon suspicion of the diagnosis, all patients must be treated pharmacologically to reduce the blood pressure (to about 110 mm Hg systolic), the heart rate (to 60–70 bpm), and the force of cardiac ejection (dp/dt). The patient should be carefully monitored and must undergo diagnostic testing as soon as possible to establish or exclude the diagnosis.
   b. Recommended antihypertensive regimens include a β-blocker (esmolol, metoprolol, or labetalol) with or without addition of sodium nitroprusside (see Table 11.8, page 576, for doses). Clevidipine is also helpful. Aggressive management up to the time of surgery is essential to prevent rupture.
2. **Examination**
   a. A careful pulse examination may indicate the extent of the dissection. Particular attention should be paid to the carotid, radial, and femoral pulses. Differential upper-extremity blood pressures in a young patient with chest pain is a strong clue to the presence of a dissection. Cardiac evaluation may reveal the presence of an AR murmur.
   b. A detailed preoperative neurologic examination is essential because a deficit recognized postoperatively may have been present at the time of presentation. A change in neurologic status may indicate progressive compromise of cerebral perfusion that can resolve with emergency surgery. However, cerebral malperfusion during CPB may also cause a significant cerebral insult. Evidence of renal dysfunction (rising BUN or creatinine, oliguria) or bowel ischemia (abdominal pain, acidosis) may necessitate modification of the surgical approach. Recurrent chest or back pain usually indicates extension, expansion, or rupture of the dissection.

3. **Diagnostic tests**
   a. The chest x-ray will usually demonstrate either a widened mediastinum or irregularity of the aortic contour, but may be normal in up to 30% of patients with a type A dissection (Figure 2.1).[314] Mediastinal width can be difficult to assess on a portable chest x-ray obtained in the emergency room, so the clinical presentation should take precedence in determining the need to obtain more definitive imaging.
   b. In a patient with severe chest pain, one might suspect that an abnormal ECG would be more consistent with an ACS, and a normal ECG would suggest the diagnosis of dissection. However, IRAD data showed that only 30–40% of patients with type A dissections had a normal ECG. Nonspecific ST changes were noted in about 40% of patients and about 20% had ischemic changes, possibly related to coronary ostial involvement with the dissection.
   c. In most hospitals, a **CT scan with contrast** is performed first. It has about 90% sensitivity and specificity in identifying an intimal flap and differential flow into true and false lumens (Figures 2.32 and 2.33). Volume-rendered imaging can provide beautiful images of aortic dissections (Figure 2.34) and can demonstrate branch artery compromise as well.
   d. **TEE** is the best procedure for identifying intimal flaps, evidence of tamponade, and AR (Figure 2.27).
      i. If the diagnosis of a type A dissection is unequivocal on CT scanning, TEE is best deferred until the patient is anesthetized in the operating room. If the diagnosis is in doubt, TEE should be performed very **cautiously** because sedation may lead to hypotension in a patient with a pericardial effusion, and acute hypertension in an inadequately sedated patient could precipitate rupture. A TTE may be valuable in ruling out a significant pericardial effusion before proceeding with a TEE.
      ii. Note that a pericardial effusion identified by CT scanning or echo usually indicates oozing of blood through the adventitia and not a free rupture. The accumulated blood under mild pressure may tamponade small bleeding sites through the aortic wall. It is generally recommended that pericardiocentesis should not be performed in this situation due to the fear of precipitating free rupture by increasing the pressure gradient between the aorta and pericardial space. Nonetheless, in salvage situations, especially in smaller hospitals without cardiac surgical availability, a controlled pericardiocentesis could prove life-saving.[326,327]
   e. **Magnetic resonance imaging (MRI)** may be the most sensitive and specific diagnostic technique to identify a dissection, but only rarely can it be obtained on an emergency basis (Figure 2.39). Furthermore, there are usually limitations to its performance in a patient requiring careful monitoring and IV drug infusions.
   f. There is little role for aortography in the evaluation of an acute dissection, Malperfusion of visceral vessels in the abdomen can be identified by CT angiography.
   g. Coronary angiography is usually not indicated in cases of acute aortic dissection, because of the necessity for emergent surgical repair. However, evidence of significant ECG changes may sometimes lead to coronary angiography as the initial diagnostic test, only to find that coronary ostial compromise is caused by an aortic dissection. In contrast, coronary angiography is helpful in planning surgical strategy in patients with chronic dissections.

E. Surgical procedures

1. Type A dissections

a. Repair involves resuspension or replacement of the aortic valve (if AR is present), resection of the intimal tear, and placement of an interposition graft to reapproximate the aortic wall (Figure 1.23). BioGlue (CryoLife) can be used to improve tissue integrity for grafting. If the root is destroyed and cannot be reconstructed, a Bentall procedure (valved conduit) is performed. If the tear extends across the arch or the tear originates in the descending thoracic aorta, consideration should be given to replacing the entire arch, often with a frozen elephant trunk (endograft) placed distally, using standard techniques of cerebral perfusion to protect the brain.[328] In experienced centers, a "total aortic repair" does not appear to increase mortality and should improve long-term outcomes by reducing the need for subsequent intervention.[329,330] Patients with visceral malperfusion have a high mortality rate and may benefit from a fenestration procedure prior to repair of the ascending aorta.[331] Iliofemoral malperfusion may require an additional revascularization procedure after the ascending aorta is replaced.

b. Repair of type A dissections should usually be performed during a period of deep hypothermic circulatory arrest (DHCA), but performing the distal anastomosis with a clamp on the distal aorta is feasible in selected cases.[332] A variety of cannulation sites for bypass have been described, most commonly using the axillary or femoral artery. Although there is a potential risk of cerebral malperfusion with initial femoral cannulation, results have been comparable with both of these approaches.[333,334] If the patient has cardiac tamponade, cannulation for and even initiation of CPB prior to opening the pericardium may be indicated, because release of tamponade could trigger free rupture and exsanguination before going on bypass.

c. Dissections with arch tears but no ascending aortic involvement are often treated as type B dissections with medical management alone. IRAD data suggest that surgical mortality exceeds medical mortality in this group of patients because the operation is more complex.[335]

d. Tears in the arch or descending aorta that extend retrograde to involve the ascending aorta are challenging. They should be managed by an ascending aorta and arch repair via a median sternotomy and placement of a frozen elephant trunk in the descending aorta.[328,336]

e. A retrograde dissection occurring after placement of an endovascular stent for a type B dissection is a difficult problem that may be managed by total arch replacement and placement of a frozen elephant trunk with partial preservation of the previous thoracic endovascular aortic repair (TEVAR) stent.[337]

2. Type B dissections

a. The traditional surgical approach to complicated type B dissections involves resection of the intimal tear and interposition graft replacement to reapproximate the aortic wall. The risk of paraplegia is greater than in patients with atherosclerotic aneurysms because less collateral flow is present. Thus, measures to reduce spinal cord ischemia by maintaining distal perfusion should be taken (see pages 81–82). Visceral malperfusion may improve with restoration of flow into the true lumen. Otherwise, a percutaneous fenestration procedure to produce a communication between the true and false lumen or additional grafting may be necessary to improve organ system or distal limb perfusion.

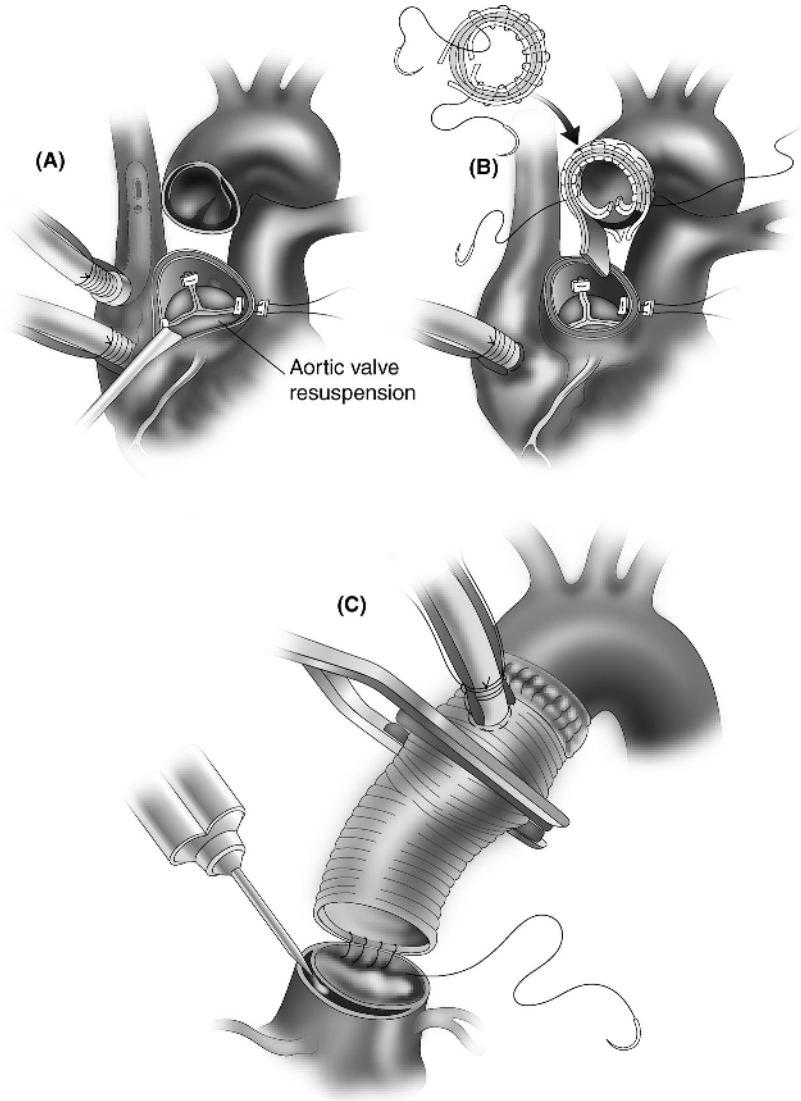


Figure 1.23 • Repair of a type A aortic dissection. (A) The aorta is opened and the entry site is resected. The aortic valve is resuspended. (B) The proximal and distal suture lines are fragile and are reinforced. During circulatory arrest with the aorta unclamped, two felt strips are shown for the distal suture line, being placed inside the true lumen and outside the adventitia. (C) After the distal suture line is completed, the graft is cannulated to reestablish antegrade cardiopulmonary bypass flow with proximal application of a cross-clamp. BioGlue may be injected to stabilize the distal and proximal (shown here) suture lines, and the proximal graft anastomosis is performed, again using felt reinforcement.

b. Owing to the substantial morbidity and mortality associated with surgical repair, endovascular stenting (TEVAR) is the recommended approach for complicated type B dissections, if feasible.[322–325] This procedure should seal the entry site to allow for thrombosis of the false lumen. Additional fenestration and stenting may be required if reconstitution of true channel flow does not correct malperfusion. Because of the high rate of progression of uncomplicated type B dissections to malperfusion and aneurysm formation (up to 50% in IRAD studies), TEVAR is recommended for patients with "high-risk" uncomplicated dissections to promote false lumen thrombosis and aortic remodeling. The aorta tends to retain adequate plasticity to achieve adequate remodeling for three months, so the best results are achieved with a TEVAR within that timeframe.[323]

XII. Thoracic Aortic Aneurysms

A. Pathophysiology. Ascending aortic (AAo) aneurysms usually result from medial degeneration whereas those in the distal arch, descending thoracic, and thoracoabdominal aorta are generally atherosclerotic in nature. Aneurysms in any location may result from expansion of chronic dissections. Although progressive enlargement may result in compression of adjacent structures, most deaths result from aneurysm rupture or dissection.[310,311]

B. Indications for surgery: Ascending aortic aneurysms

1. Guidelines for prophylactic resection of ascending aortic aneurysms are based on natural history studies which have primarily correlated aortic size with the risk of adverse aortic events (AAEs), which include rupture, dissection, or death. The latter is a confusing endpoint because death from non-aortic causes may be considered an AAE, and patients who die from dissections or rupture are included twice. These studies have not included other potentially relevant contributory factors, such as aortic stiffness or distensibility. Nonetheless, there are concerns that size criteria may not be applicable to all adult patients and should be modified based on either the patient's body surface area (the indexed aortic size) or, preferably, just the patient's height.
2. The published risk of rupture or dissection differs only slightly in the literature, and suggests that these risks are quite low in aortas measuring <5.5 cm (Figure 1.24).

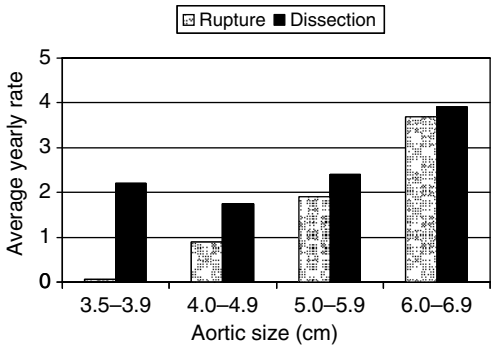


Figure 1.24 • Risk of aortic dissection or rupture based on the initial aortic size. (Adapted from Davies et al., *Ann Thorac Surg* 2002;73:17–27.)

A 2018 report from the Aortic Institute at Yale-New Haven Hospital of 780 patients with ascending aortic aneurysms showed that the annual dissection rates were 1.2, 2.0, and 1.8% for aneurysms measuring 4.0–4.4, 4.5–4.9, and 5–5.4 cm in size, respectively, with rupture alone being very rare.[338] Similarly, a study from Boston reported that the five-year risks were 0.4, 1.1, and 2.9% for aortas measuring 4.5, 5.0, and 5.5 cm, respectively.[339] Surgery was recommended when the estimated risk of adverse events exceeded the surgical risk, which may vary depending on the experience of the surgical team. Notably, it was found in the latter study that these risks were independent of whether the patient had a bicuspid valve or not.

3. Indications for surgery per ACC guidelines are based solely on aortic size.
   a. Class I indications
      - Aortic root or ascending aorta >5.5 cm.[340] Although these guidelines are provided for patients with bicuspid valves, they should apply to those with trileaflet valves as well. This recommendation differs from a prior joint committee class I recommendation to perform surgery for an aorta >5.5 cm if there is no genetic disease, but for an aorta >5 cm for genetically associated disorders, including a bicuspid valve.[341]
      - Aorta ≥4.5 cm in Marfan syndrome
      - Aorta ≥4.2 cm in Loeys–Dietz syndrome (2010 recommendation)
      - Acute type A aortic dissections
   b. Class IIa indications
      - Aortic root ≥5 cm if there is a family history of aortic dissection, an aortic growth rate >0.5 cm/year, or for patients with a low surgical risk (<4%) operated on by an experienced surgical team.[342] Again, although written for patients bicuspid valves, this should also apply to patients with trileaflet valves.[343] It has been noted that familial cases of dissection tend to occur at younger ages and have faster aortic growth rates with a threefold greater risk of dissection. Thus, it is not unreasonable to consider prophylactic aortic replacement at smaller sizes than recommended in the ACC guidelines in these patients.[344]
      - Aneurysms ≥4.5 cm if an operation is indicated for aortic valve pathology. One study showed that the risk of developing an aortic dissection following AVR was more than 25% if the aortic size exceeded 5 cm at the time of AVR, but current recommendations are to replace an aorta ≥4.5 cm, probably for both bicuspid and trileaflet valves.[345]
4. Acceptance of these guidelines is confounded by IRAD data showing that 60% of aortic dissections were noted to occur in aortas measuring <5.5 cm and 40% occurred when the aorta was <5 cm in diameter.[346] Furthermore, studies have shown that aortic dimensions tend to be 7 mm larger after a dissection occurs, suggesting that surgery for smaller aortas may be justifiable.[338]
   a. Using the "one size fits all" guidelines for resection, independent of the patient's size, may not provide an accurate assessment of risk. The Yale group initially introduced the concept of the aortic size index (ASI), which was the aortic diameter divided by the body surface area (BSA) (Appendix 17).[347] They found that the risk of adverse events was low for an ASI <2.75 cm/m^2, moderate for an ASI of 2.75–4.25 cm/m^2, and significant once the ASI

exceeded 4.25 cm/m^2. For short women with Turner's syndrome, an ASI >2.5 cm/m^2 is considered significant and an indication for surgery.[348]

b. However, further analysis suggested that height, rather than BSA, was a more accurate predictor of AAE. The aortic cross-sectional area/height ratio (πr^2/ht in meters) was proposed in 2002, with a value >10 producing a higher risk for dissection, and this became a level IIa indication for surgery in the 2010 and 2013 STS guidelines.[341,349] Although this was initially applied to patients with Marfan syndrome and bicuspid valves,[350,351] it was later found to be applicable to patients with trileaflet valves as well.[343] Of interest was that 42% of patients with trileaflet valves with aortas measuring 4.5–5.5 cm in diameter, which was below the 5.5 cm resection guidelines, had a height ratio >10.[343]

c. Subsequently, the Yale group reported that the aortic height index (AHI) was found to have a better correlation with AAE than the ASI.[338] The AHI was the aortic size in centimeters divided by the patient's height in meters. The risk was greater when the AHI exceeded 2.43 cm/m^2 (Appendix 18). Notably, the low-risk patients in this study had a composite 4%/year risk of dissection, rupture, and death, but the latter also included nonaortic deaths.

d. The Yale group then reported that ascending aortic length (AAL), which measured the centerline distance between the aortic annulus and the innominate artery, strongly correlated with the risk of AAE.[352] They derived a new metric termed the length height index (LHI) that indexed the AAL to the patient's height. They found that the risk of AAE was five times greater with an AAL ≥13 cm compared with an AAL <9 cm, and was also five times greater when the LHI was ≥7.5 cm/m compared with <5.5 cm/m. In their latest report, they renamed the AHI as the diameter height index (DHI) and redefined the AHI as the DHI + LHI to incorporate the concept of aortic length (Appendix 19). Utilizing this concept depends on an accurate measurement of aortic length, which is not routinely measured on CT angiograms in most hospitals. They found that the risk of AAE was low for an AHI <9.33, and then increased progressively for AHIs of 9.38–10.81, 10.86–12.50 and ≥12.57 cm/m.[352]

C. Indications for surgery: arch and descending aortic aneurysms

1. Arch aneurysms – all are class IIb indications per the joint guidelines.[341]

- Ascending aortic aneurysms that warrant surgery with extension into the arch. This should entail resection of the ascending aorta and partial arch replacement using DHCA with axillary inflow to allow for antegrade cerebral perfusion (ACP). It should be noted that the "aortopathy" associated with bicuspid valves tends to involve the arch in 75% of patients, and hemiarch or arch replacement should be considered in these patients.[353] A growth rate >0.5 cm/year or the development of symptoms is an indication for surgery.
- Replacement of the entire arch is reasonable for an acute dissection with an intimal tear in the arch, or when there is evidence of arch expansion, extensive tissue destruction, leakage, or rupture.[328–330] It is also reasonable for chronic dissections with arch enlargement and distal arch aneurysms extending into the descending thoracic aorta. Note that the presence of an arch tear with ascending aortic involvement mandates surgery, but medical therapy can be considered if the ascending aorta is not involved.[335]
- Isolated degenerative or atherosclerotic aneurysms >5.5 cm in diameter.

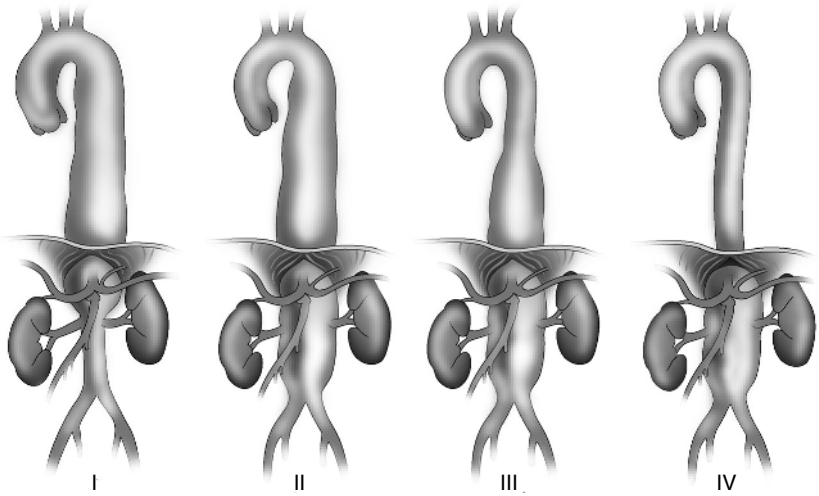


Figure 1.25 • Crawford classification of thoracoabdominal aneurysms.

2. **Descending thoracic (DAo) and thoracoabdominal aneurysms** (see Figure 1.25 for classification) – all of the below are class I indications for intervention; endografting is preferable when feasible.
   - Symptomatic aneurysms
   - Thoracic aneurysms ≥5.5 cm in diameter (atherosclerotic or chronic dissections) and thoracoabdominal aneurysms >6.0, but smaller in patients with connective tissue disorders.
   - Complicated acute type B dissections and uncomplicated type B dissections at high risk for distal expansion.[323]

D. Preoperative considerations

1. Preoperative risk assessment is very important in patients undergoing resection of aortic aneurysms, especially descending aneurysms which carry higher risk.
2. Coronary angiography should be performed prior to all elective surgery in patients over age 40. It should also be performed on all patients prior to ascending aortic and arch surgery to identify coronary dominance and anatomy, since coronary button implantation is necessary in most procedures.
3. A careful preoperative baseline neurologic evaluation is important because of the risks associated with circulatory arrest (stroke, seizures) and aortic cross-clamping for surgery (the risk is highest for type II aneurysms) or with endograft coverage of intercostal arteries (paraplegia). A detailed informed-consent discussion with the patient about these devastating complications is essential and must be documented.
4. Pulmonary status must be optimized prior to surgery. Many patients with descending aortic aneurysmal disease have concomitant COPD, and the use of a thoracotomy incision, lung manipulation during surgery, anticoagulation, and multiple blood transfusions may have a detrimental effect on pulmonary function.

5. Renal function must be monitored carefully after angiography, especially in diabetic patients. The creatinine should be allowed to return to baseline before surgery to reduce the risk of renal dysfunction associated with aortic cross-clamping. Preoperative hydration may be beneficial.
6. CT angiography is essential to identify the extent of the aneurysm and potential landing zones. An assessment of aortoiliac disease is essential prior to any endovascular stenting procedure. Severe stenosis, tortuosity, or extensive atherosclerotic disease may necessitate an alternative site for arterial access or may lead to abandonment of the proposed procedure.

E. Surgical procedures

1. Ascending aortic aneurysms

a. Supracoronary interposition graft placement is performed if the aneurysm develops above the sinotubular junction, thus sparing the segment from which the coronary arteries arise.

b. If the sinuses are aneurysmal, they should be resected and replaced. For patients with moderate–severe aortic valve pathology, a valved conduit (Bentall procedure, Figure 1.11), using either a mechanical valved conduit, a manually constructed bioroot (sewing a tissue valve into a tube graft), or a stentless miniroot can be performed (Figure 1.9).[354,355] However, if there is minimal valve pathology or valve repair is feasible, an aortic valve-sparing operation should be considered, even in patients with Marfan syndrome or bicuspid valves (Figure 1.14).[356,357] The design of this procedure depends on the extent of the aneurysm and the pathophysiology of AR.

c. CPB is required for repair of AAo aneurysms. Depending on the site of the distal anastomosis, simple aortic cross-clamping or a period of DHCA may be necessary. Arterial access for CPB can be achieved through the aneurysm if DHCA is to be used, since that section of the aorta will subsequently be resected. Antegrade perfusion is then reinitiated either through a side arm limb of the graft or with direct cannulation through the graft. Alternatively, femoral or axillary artery cannulation can be used. The latter can provide ACP during a period of circulatory arrest and avoids potential retrograde embolization of atherosclerotic debris that may occur with retrograde femoral flow.

d. For DHCA, the central core temperature should be lowered to 18–20 °C, at which time there is presumed to be electroencephalographic silence. This should provide 45 minutes of safe arrest with minimal risk of neurologic insult. Adjuncts to improve cerebral protection during a period of DHCA include methylprednisolone 30 mg/kg, packing the head in ice, and either continuous retrograde cerebral perfusion (RCP) through the superior vena cava (SVC) or preferably antegrade cerebral perfusion (ACP) directly or through the axillary artery.[358–363] With the latter approach, the operation can be done at moderate systemic hypothermia.[361]

2. Transverse arch aneurysms

a. Hemiarch repair using DHCA with RCP or ACP is performed if the ascending aorta and proximal arch are involved. A graft is sewn to the undersurface of the arch leaving the brachiocephalic vessels attached to the native aorta.

b. Extended arch repair involves placement of an interposition graft sewn to the proximal descending aorta with reimplantation of a brachiocephalic island during a period of circulatory arrest. Alternatively, a debranching operation

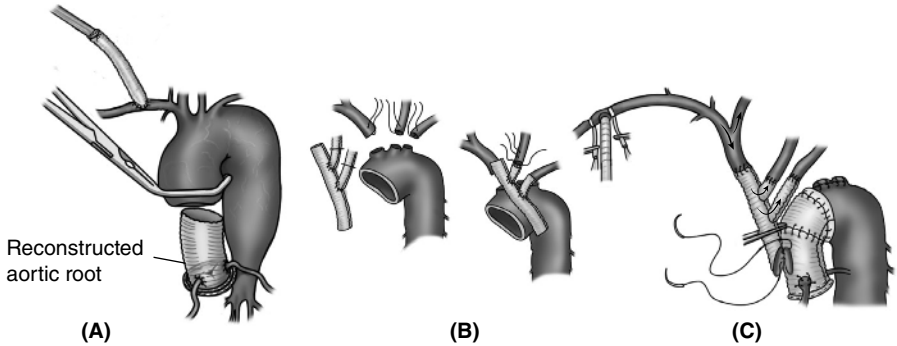


Figure 1.26 • Aortic arch replacement using a trifurcation graft (TG). (A) Using axillary cannulation for CPB, the aorta is clamped and the proximal root reconstruction is performed. (B) During DHCA, the arch vessels are divided 1 cm from their origins, and individual anastomoses are sequentially performed to the arch vessels with side limbs off the TG. (C) Flow is then restored to the brain with a clamp on the proximal segment of the TG. The distal arch anastomosis is constructed and the two aortic grafts are reapproximated. Finally, the TG is sewn to the proximal portion of the aortic graft.

with use of individual trifurcation grafts to the arch vessels may be performed. This should reduce the duration of DHCA and improve cerebral protection, potentially reducing neurologic morbidity (Figure 1.26).[364,365]

c. Distal arch repair can be performed via a left thoracotomy without cardiopulmonary bypass, but left heart bypass or CPB are commonly used. A period of DHCA may be useful when clamping is not feasible for the proximal anastomosis or for more complex operations. Endografting with carotid or subclavian artery bypass grafting can be considered in select cases.

d. If it is anticipated that a surgical descending aortic repair may be necessary in the future, a piece of graft material is left dangling from the distal anastomosis and can be retrieved at a subsequent operation through the left chest (the "elephant trunk" procedure).[366] The frozen elephant trunk procedure places a stent graft distally at the time of the arch repair, and distal stenting may be performed later.[367]

3. Descending thoracic aorta

a. Open graft replacement of the diseased aorta is performed with reimplantation of intercostal vessels at the level of T8–T12 for more extensive aneurysms. This is performed through a left thoracotomy or thoracoabdominal incision with use of one-lung anesthesia.

b. Consideration should be given to the use of adjuncts (medications, cerebrospinal fluid [CSF] drainage, shunting) to prevent spinal cord ischemia during the period of aortic cross-clamping or during extensive endograft placement to reduce the risk of paraplegia.[368–370] During surgical procedures, shunting can be accomplished by draining blood from a site proximal to the aortic cross-clamp (inferior pulmonary vein/left atrium/proximal aorta) and returning it distally (distal aorta/femoral artery) to perfuse the spinal cord and kidneys. A Biomedicus centrifugal pump, which actively returns blood to the patient at a designated rate, can be used with or without oxygenation. Left heart bypass

alone has been shown to reduce the incidence of paraplegia during surgery for thoracoabdominal aneurysms, but not necessarily for more limited descending thoracic aneurysms.[371]

c. Because of the inherent risk of descending aortic clamping, TEVAR has become popularized for the treatment of descending thoracic and thoracoabdominal aneurysms. This requires careful evaluation of the aorta by CT or MR imaging for landing zones and is performed using transfemoral access. Although paraplegia remains a risk of this procedure, TEVAR may reduce the risk of early death and postoperative complications, including acute kidney injury, bleeding, pneumonia, and cardiac morbidity.[372–374]

d. Femorofemoral bypass can be used to provide distal protection. It can also be used along with DHCA when clamping is not possible due to extensive disease or calcification. This technique also provides visceral and spinal cord protection.

e. Arterial monitoring lines are inserted in the right radial and femoral arteries to monitor proximal and distal pressures during the period of aortic cross-clamping, especially if left heart bypass is used.

XIII. Atrial Fibrillation

A. Pathophysiology[188]

1. Atrial fibrillation (AF) results from the presence of multiple reentrant circuits that prevent the synchronous activation of adequate atrial tissue to generate mechanical contraction. Focal triggers promote sustained reentry. Atrial distention may predispose to this arrhythmia, which then promotes progressive atrial dilatation and remodeling, leading to permanent AF. AF can lead to:

a. Loss of atrioventricular (AV) synchrony, which reduces ventricular filling and stroke volume. This can produce dizziness, fatigue, and shortness of breath, especially in hypertrophied hearts and when the ventricular rate is high.

b. Thrombus formation in the left atrial appendage with a predisposition to thromboembolism and stroke

c. Symptoms of an irregular heartbeat (palpitations)

d. A cardiomyopathy if the rate is not controlled

e. Long-term cognitive dysfunction

2. AF may occur as an isolated entity ("lone AF") in patients with no structural heart disease or in patients with underlying heart disease. It is more common in older patients and those with hypertension, valvular heart disease, or coronary disease. It is categorized as:

a. Paroxysmal: recurrent AF (two or more episodes) that terminates spontaneously or with an intervention within seven days. In these patients, the atrial foci that serve as the trigger are usually located in the tissue surrounding the pulmonary veins as they enter the left atrium.

b. Persistent: lasts >7 days and responds to pharmacologic or electrical cardioversion. The reentrant circuits usually originate in the left atrium.

c. Long-standing persistent or permanent: fails to respond to medications or cardioversion and lasts over one year.

B. Management considerations and indications for surgery

1. AF is managed with medications to control the ventricular rate (β-blockers, calcium channel blockers, amiodarone), potentially convert the patient to sinus rhythm, and prevent thromboembolism (warfarin or a non-vitamin K antagonist oral anticoagulant [NOAC]). When surgery is being considered, rate-control medications should be continued up to the time of surgery. NOACs should be stopped 36–48 hours prior to surgery and warfarin should be stopped five days prior to surgery. Bridging anticoagulation is indicated in patients at high risk for embolic stroke, including those with a CHA_2DS_2-VASc score ≥5 (see Appendix 10 A), stroke or systemic embolism within three months, or rheumatic MS.
2. When the ventricular rate cannot be controlled, symptoms are disabling, or anticoagulation cannot be tolerated or is not desirable, an ablative procedure should be considered.[375,376] Catheter ablations are very successful in ablating paroxysmal AF arising from the pulmonary veins, and with adequate mapping, reasonable success (60%) can be achieved in patients with persistent AF. In patients with long-standing persistent AF in whom anticoagulation is high risk or not desirable, a transcatheter procedure to exclude the left atrial appendage (Watchman device, Lariat) can be considered (Figure 1.27).[377,378] This may

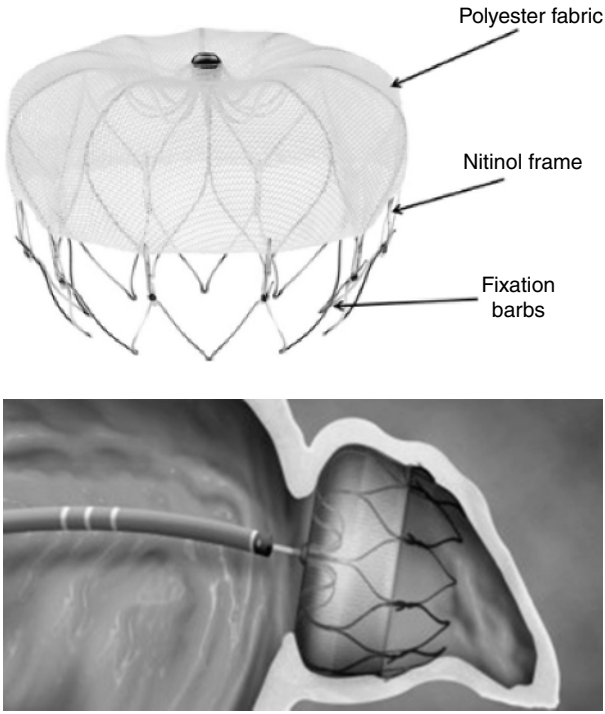


Figure 1.27 • The Watchman device is positioned at the orifice of the left atrial appendage to prevent formation of left atrial appendage thrombus. It endothelializes fairly quickly, but short-term use of warfarin is recommended. (Image courtesy of Boston Scientific Corporation (A), http://azheartrhythmcenter.com/resources/procedure-instructions/watchman-device/ (B).)

allow the patient to be off long-term anticoagulation, although a short course of warfarin is indicated after placement of a Watchman device.

3. The ability to restore sinus rhythm with an ablation performed as a stand-alone procedure or during concomitant cardiac surgery improves symptoms, quality of life, and long-term survival, and may reduce the incidence of stroke.[376] Stroke risk is also reduced by more than 50% simply by excluding the left atrial appendage without performance of an ablation procedure. Numerous societies have provided recommendations for ablative procedures. The 2017 STS practice guidelines make the following recommendations for surgical ablation:[188]
   a. Class I – As a concomitant procedure during CABG, aortic, or mitral valve surgery.
   b. Class IIa
      - As a stand-alone procedure for symptomatic AF in the absence of structural heart disease that is refractory to class I/III antiarrhythmic drugs or catheter ablation.
      - As a stand-alone Cox-Maze IV procedure for symptomatic persistent or long-standing AF in the absence of structural heart disease.
      - Left atrial appendage excision during surgical ablation or without ablation in the patient undergoing other cardiac operations.

C. Surgical procedures

1. In 1987, Cox designed a technically complex "cut-and-sew" operation called the "Maze" procedure that was designed to ablate AF, restore AV synchrony, and preserve atrial transport function. Subsequent iterations led to the Cox-Maze III operation, which included incisions that not only interrupted the micro-reentrant circuits but also allowed the sinus node to function, and directed propagation of the sinus impulse through both atria. AF was eliminated in about 90% of patients, but about 10% of patients required pacemakers.
2. Ablation technologies, primarily using cryoablation and radiofrequency, have been developed to mimic the suture lines of the Cox-Maze III lesion set, then called the Cox-Maze IV.[379–381] To achieve success, the lesions created must achieve transmurality.
   a. Since the left atrium is usually the primary focus of reentry, a left-sided Maze is most commonly performed, but most studies suggest that a biatrial Maze procedure is more successful in eliminating AF.[382–384] However, it is associated with more bleeding and a higher rate of pacemaker implantation, related primarily to sinus node dysfunction.[384]
   b. Success rates are lower with large left atria, advanced patient age, and pre-existing long durations of AF, although use of cryoablation rather than radiofrequency may mitigate failure rates.[188,385,386] One study found that the two-year risk of recurrence of AF was 20% greater for each one-year increase in preoperative AF duration due to more advanced tissue remodeling.[386] The likelihood of recurrence progressively increases when the left atrial size exceeds 5 cm.[387]
   c. Although these techniques have virtually completely supplanted the "cut and sew" Maze, a comparative study found that they had higher failure rates.[388]
3. For patients with paroxysmal AF, bilateral pulmonary vein isolation (PVI) with obliteration of the left atrial appendage is usually successful. This can be

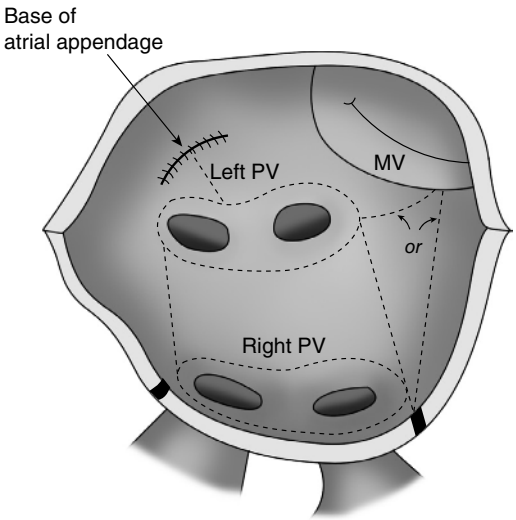


Figure 1.28 • The left-sided Maze involves ablation lines that encircle and connect the right and left pulmonary veins and one that extends from the inferior box lesion near the right or left inferior pulmonary vein to the mitral valve annulus. The left atrial appendage is amputated and an additional ablation line is placed from the base of the appendage to the left pulmonary veins. The base of the left atrial appendage is then oversewn.

achieved with endocardial catheter ablation, bilateral thoracoscopic approaches with epicardial ablation, or concomitantly with other cardiac operations. Bilateral PVI is more successful after AVR than mitral valve surgery, often because the left atrium is smaller.[188]

4. For patients with persistent AF undergoing mitral valve surgery, the optimal lesion set for surgical ablation is somewhat controversial. Meta-analyses have suggested that freedom from AF is greater with a biatrial Maze than a left atrial Maze, but some studies found equivalent benefit.[382–384,389,390] One study reported that the freedom from AF (about 60–65%) was comparable with bilateral PVI and biatrial Maze procedures, but the requirement for a permanent pacemaker was 21.5% with an ablation procedure.[391] Although bilateral PVI is generally considered an inadequate operation for persistent AF, this report would seem to justify performing bilateral PVI with LA appendage excision during AVR or CABG, although better success rates can be achieved with a full left atrial Maze.[392,393]
5. **Left atrial Maze.** Persistent AF should generally be treated at a minimum by a left atrial Maze procedure (Figure 1.28). This is most commonly performed in association with mitral valve surgery, since 30–50% of these patients have preoperative AF.[391] This procedure produces ablation lines that encircle and connect the right and left pulmonary veins ("box lesion"), and one that extends from the inferior pulmonary vein ablation line to the mitral valve annulus. The left atrial appendage is amputated and an ablation line is placed through the base of the appendage to the left pulmonary vein encircling line. Left atrial volume reduction may be helpful when the LA dimension exceeds 6 cm.[394] Use of ganglionic plexi mapping and ablation with confirmation of

conduction block by pacing may improve results.[395] With use of radiofrequency ablation, the freedom from AF at two years with antiarrhythmic drugs (AAD) ranges from 65 to 85% and without drugs from 55 to 75%.[380,381,388]

6. **Right atrial Maze.** The right-sided maze includes amputation of the RA appendage (or an ablation line across its base) and an incision into the right atrium from the septum toward the AV groove. Through this incision, ablation lines are extended up the SVC and down to the IVC, across the fossa ovalis down to the coronary sinus, from the IVC to the coronary sinus, and from the sinus to the tricuspid annulus (isthmus lesions). Additional ablation lines extend from the anterior tricuspid leaflet to the base of the excised RA appendage and from the posterior tricuspid leaflet to the AV groove (Figure 1.29).
7. Exclusion of the left atrial appendage (LAA) by resection and oversewing is an integral element of any Maze procedure.[396] It has a level IIa indication in patients with AF undergoing a PVI or other cardiac procedure without an ablation.

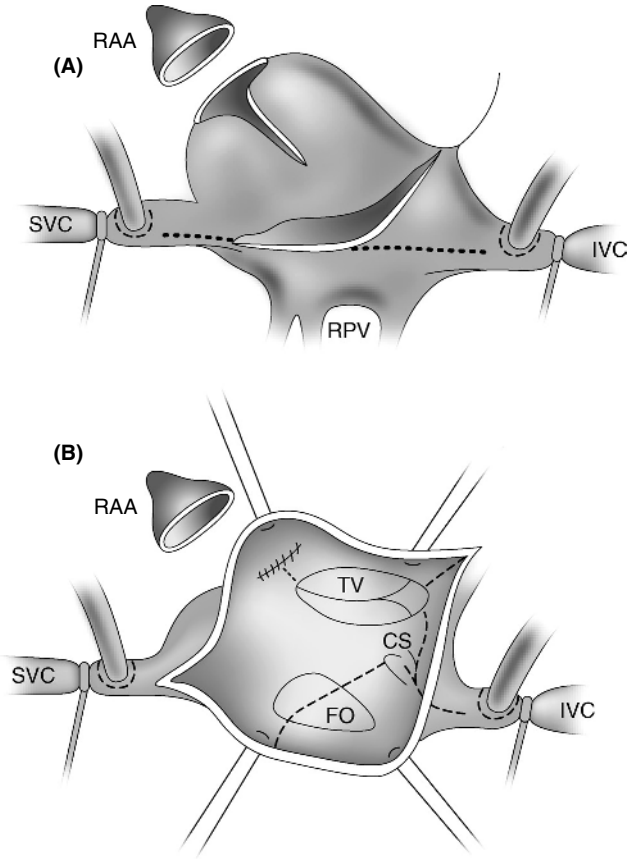


Figure 1.29 • (A) The right-sided Maze includes ablation of the base of the right atrial appendage and an incision in the right atrial wall through which multiple bipolar and unipolar ablation lines can be carried out. (B) Sites for endocardial ablation are shown by the dotted lines (see text).

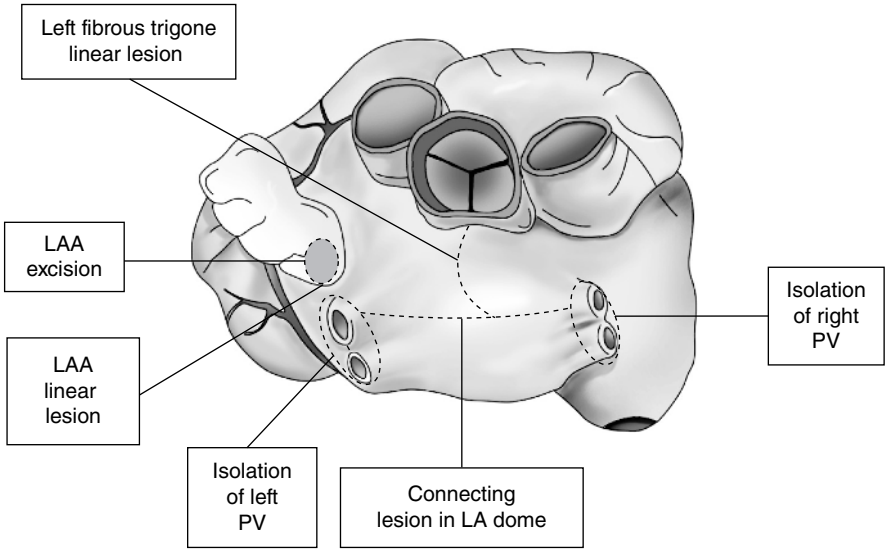
a. Despite evidence that LAA resection significantly reduces the risk of thromboembolic stroke, the risk still persists even if sinus rhythm has been restored and there has been satisfactory obliteration of the LAA. One study found that, even with a return to sinus rhythm, lack of LA mechanical contraction was noted in 30% of patients after a Maze procedure and increased the risk of stroke fivefold. In addition, a large left atrium (LA volume index ≥33 mL/m^2) increased the risk of stroke threefold. Therefore, it was recommended that anticoagulation should be utilized if either of these two findings was identified, even if sinus rhythm has been restored.[397]

b. Resection of the LAA along with a Maze procedure has even been proposed for patients in sinus rhythm undergoing mitral valve surgery with a large left atrium or more than mild TR in whom there is an increased long-term risk of developing AF.[215] It is not clear if LAA resection alone can be justified for routine open-heart operations just because of the 25% incidence of postoperative AF, which is usually self-limited.

8. For patients with "lone" persistent AF and indications for an ablation, minimally invasive surgical approaches are often considered when catheter ablation has failed. Among the various procedures that have been described are the following:

a. **Bilateral thoracoscopic approaches** generally allow for epicardial PVI using radiofrequency ablation and resection of the left atrial appendage.

b. **Dallas lesion** set (Figure 1.30). This is an epicardial procedure performed through minimal access incisions that isolates and interconnects the pulmonary



LAA = left atrial appendage; PV = pulmonary veins

Figure 1.30 • Epicardial lesion set for a thoracoscopic approach to atrial fibrillation. Bilateral pulmonary vein isolation and a connecting lesion between the right- and left-sided pulmonary veins are performed. In addition, a linear lesion over the dome of the left atrium is created extending from the left fibrous trigone at the anterior mitral valve annulus to the base of the junction of the left and noncoronary cusps to mimic the mitral isthmus lesion performed endocardially.

veins and places an ablation line from the left fibrous trigone across the dome of the left atrium to the base of the aortic valve, mimicking the mitral isthmus lesion of the left atrial Cox-Maze III.[398] Partial autonomic denervation and excision of the left atrial appendage can also be performed.[399]

c. **Convergent procedure** (Figure 1.31). With recognition that chronic atrial stretch and structural remodeling can cause conduction abnormalities in the posterior left atrium, a hybrid approach termed the "convergent" procedure was developed. This combined partial bilateral PVI and multiple epicardial radiofrequency posterior left atrial lesions performed through a subcostal

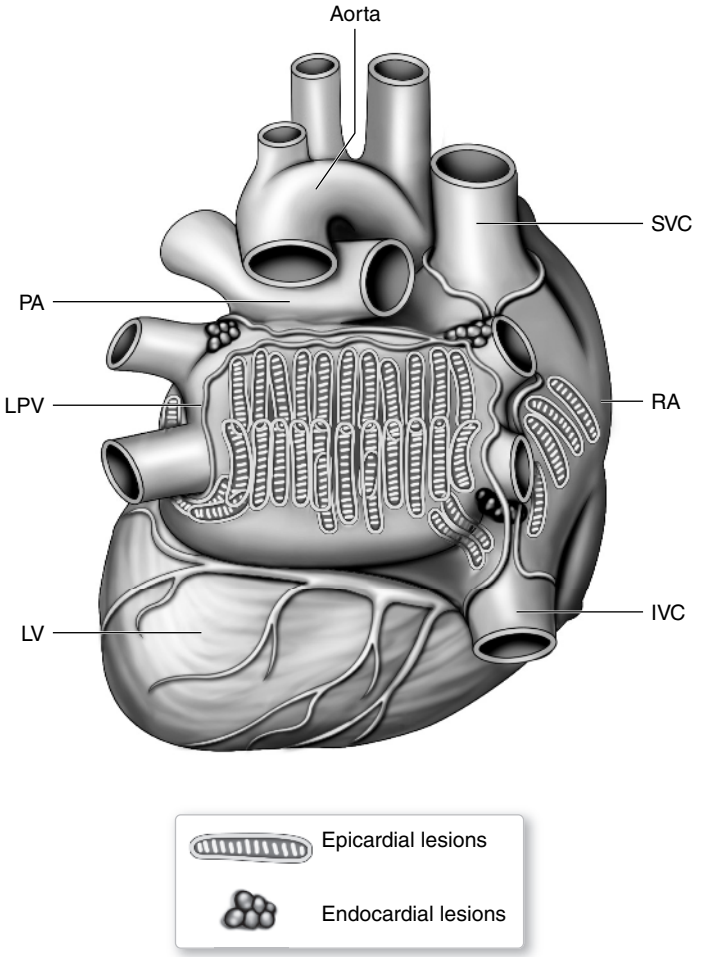


Figure 1.31 • Convergent procedure. Through a subxiphoid incision, bilateral pulmonary vein isolation is performed along with multiple interconnecting ablation lesions across the posterior left atrium. Subsequently, additional endocardial ablation over the pulmonary veins is performed. (Reproduced with permission of Gersak et al. *Ann Thorac Surg* 2016;102:1550–7.)[400]

approach with endocardial ablation lines performed by an electrophysiologist to complete the PVI.[400] This procedure has been recommended in symptomatic patients who fail medical therapy or catheter ablation and was given a level IIb indication by an expert consensus panel in 2017.[375]

XIV. Advanced Heart Failure

A. Pathophysiology. Advanced heart failure (HF) is a clinical syndrome that develops due to progressive deterioration in LV function associated with LV remodeling. It is most commonly the result of multiple infarctions from CAD (ischemic cardiomyopathy), but may result from a dilated cardiomyopathy or end-stage valvular heart disease. As ventricular function deteriorates, the LV dilates and changes from an elliptical to a spherical shape. This increases wall stress, which then increases oxygen requirements, causes pathologic cardiomyocyte hypertrophy that further compromises contractile function, and induces functional MR. These changes lead to intractable HF. In addition, ventricular remodeling increases the tendency to develop ventricular arrhythmias.[401]

1. Neurohormonal activation may contribute to remodeling. Elevation of various hormones increases sodium retention and produces peripheral vasoconstriction, increasing hemodynamic stress. There are also direct toxic effects on myocardial cells, stimulating the development of fibrosis. This relationship between neurohormonal activation and worsening of HF forms the basis of the medical approach to HF.
2. The prognosis for patients with advanced HF is quite poor, with a 50% mortality rate within one year of diagnosis. For patients in stage D, the estimated mortality rate is 80% at five years.[401]

B. Classification and treatment considerations

1. HF patients are generally divided into those with preserved ventricular function (HFpEF) and those with reduced ventricular function (HFrEF). The former usually develop diastolic HF from long-standing hypertension and the latter are associated with ischemic cardiomyopathies from MI, advanced valvular disease, or other nonischemic dilated cardiomyopathies. Systolic and diastolic components coexist in many patients.
2. The NYHA classification (Appendix 1B) assesses the patient's functional capacity and symptoms, progressing from no limitations of physical activity to more significant limitations with less and less activity and eventually at rest (stage IV)
3. The ACC/AHA guidelines have defined four stages in the progression of HF:
   a. **Stage A:** high risk for development of HF. These patients should have their risk factors (primarily hypertension) aggressively managed.
   b. **Stage B:** structural heart disease with LVH and reduced EF without HF. These patients need more aggressive medical therapy with ß-blockers, ACE inhibitors, or ARBs for hypertension, diuretics for volume overload, and an ICD for asymptomatic ischemic cardiomyopathy with an EF $\leq$30% at least 40 days post infarction.
   c. **Stage C:** structural heart disease with HF. These patients can be in NYHA class I–IV with preserved or reduced EF. Treatment includes ß-blockers, ACE inhibitors, or ARBs, and diuretics for fluid retention. CABG may be

considered for angina or extensive myocardial ischemia, and valve procedures should be offered for significant valve pathology. In patients with HFrEF who have persistent class II–IV symptoms and are in stage C or D, additional considerations include:[402]

- Addition of an aldosterone receptor antagonist (spironolactone or eplerenone)
- Substitution of an ARNI (angiotensin-receptor neprilysin inhibitor [valsartan/sacubitril]) for the ACE inhibitor or ARB
- ICD for an EF ≤35% and >40 days post MI (see page 92).
- Cardiac resynchronization therapy (CRT) if EF ≤35%, normal sinus rhythm, and QRS interval >150 ms with LBBB; this is a class I indication with several class IIa and IIb indications for patients with shorter QRS intervals and non-LBBB patterns
- Ivabradine if heart rate remains >70 in sinus rhythm on ß-blockers

d. Stage D: refractory HF requiring specialized intervention. These patients are usually in NYHA class IV and may require assist devices as a bridge to cardiac transplantation or for destination therapy.[403]

4. The INTERMACS (Interagency Registry for Mechanically Assisted Circulatory Support) profile identifies seven levels of advanced HF for patients who are in stage D with NYHA class IV (see Table 1.13 and Appendix 1D). The ROADMAP study showed that ventricular assist devices improved

Table 1.13 • INTERMACS Classification of Heart Failure

IM	Description	NYHA Class	ACC Stage	Recommended Time to MCS
1	Cardiogenic shock ("crash and burn")	IV	D	Within hours
2	Progressive decline on inotropic medications ("sliding fast")	IV	D	Within a few days
3	Stable on inotropic support ("dependent stability")	IV	D	Within a few weeks
4	Recurrent advanced HF; resting symptoms at home on oral meds ("frequent flyer")	Ambulatory IV	D	Within a few weeks–months
5	Exercise intolerance "housebound"	Ambulatory IV	D	Variable
6	Exercise limited "walking wounded"	Ambulatory IV	C–D	Variable
7	Advanced NYHA class III	IIIB	C–D	Variable

MCS, mechanical circulatory support

survival in patients with INTERMACS profile 4 and 5–7, but fewer clinical benefits were shown in profiles 5–7.[404]

C. Indications for surgery and surgical procedures. A variety of surgical procedures can be utilized to treat the patient with advanced HF, depending upon the pathology present and the degree of ventricular dysfunction.

1. Coronary bypass surgery should be performed in patients with an ischemic cardiomyopathy to reduce anginal symptoms, possibly improve ventricular function, alleviate symptoms of HF, lower the risk of sudden death, and improve survival. ACC/AHA guidelines recommend revascularization for the following:[401,402]
   a. Class I – angina and bypassable or stentable anatomy, especially LM or LM equivalent disease.
   b. Class IIa
      - Mild–moderate LV systolic dysfunction and significant LAD or multivessel disease with viable myocardium to increase survival. This recommendation is consistent with vast literature suggesting that CABG will improve survival in the patient with multivessel disease and impaired LV function. Furthermore, this benefit is more likely to occur when there is demonstration of viable myocardium in the area subtended by stenotic or occluded vessels.
      - CABG or medical therapy is reasonable to improve morbidity and mortality in patients with significant CAD, an EF <35%, and HF symptoms. Long-term follow-up data from the STICH trial did show improved 10-year survival in such patients compared with medical therapy.[18–20]
   c. Class IIb – CABG may be considered with ischemic heart disease, severe LV systolic dysfunction (EF <35%), and operable anatomy whether or not viable myocardium is present. A substudy of the STICH trial found that outcomes were not affected by whether myocardium was viable or not, especially in patients with severe LV dysfunction, for whom viability lost prognostic significance.[19]
2. Aortic valve surgery. Patients with symptomatic AS, especially with HF symptoms, have an average survival of 1–2 years.[127] TAVR and SAVR produce comparable long-term results in most patients, but TAVR is a less invasive procedure with rapid recovery and may be preferable in patients with advanced HF symptoms.
3. Mitral valve surgery
   a. Ischemic MR is an important predictor of the development of HF and of poor survival. Revascularization alone may be beneficial in reducing the degree of MR with acute ischemia, but is less likely with chronic ischemic MR. Whether there is any survival benefit to addressing MR with a restrictive mitral annuloplasty at the time of CABG in patients with moderate–severe LV dysfunction remains controversial, although there may be some improvement in symptoms.[200–207,405]
   b. The 2013 ACCF/AHA guidelines for management of HF considered mitral valve surgery or percutaneous mitral repair as class IIb indications in stage D patients due to uncertain benefit.[401] For patients with dilated cardiomyopathies, placement of a small restrictive annuloplasty ring has been shown to promote reverse remodeling (usually a reduction in end-systolic volume index >15%), restore normal geometric relationships, and may alleviate symptoms of HF. Improvement in long-term survival is less evident, but has been demonstrated

in some studies.[405–409] Results may depend on ventricular size, since poor results have been noted with severely dilated ventricles (LV end-diastolic dimension >65 mm) and in many patients with nonischemic cardiomyopathies.[410]

c. Studies comparing mitral valve repair and replacement for patients with severe ischemic MR showed comparable two-year survival rates of about 80%, but a high rate of recurrence with mitral valve repair (58% vs. 3%). There was a significantly higher risk of HF-related adverse events with mitral valve repair as well (58% vs. 3%). These studies did not use medical therapy as a control arm and patients did not undergo CABG.[204]

d. Although the MitraClip was initially approved for patients with degenerative MR, several studies have demonstrated benefits in patients with advanced HF from functional MR. As discussed in the section on MR (pages 49–50 and 53–55), two trials published in 2018 found improvement in symptoms and reduced rehospitalization compared with medical therapy, but only one of the two supporting trials showed a survival benefit, which was evident in patients with more severe MR but less advanced LV dysfunction.[209,210] Therefore, it was concluded that MitraClip could reduce HF readmissions and mortality if applied to patients with persistent NYHA class II–IV on GDMT, including CRT, if appropriate, with ≥3+ MR (EROA ≥30 mm^2 and/or RV ≥45 mL) with an LVEF of 20–50% and LVESD <70 mm.[211]

4. Cardiac resynchronization therapy (CRT) (atrial-synchronized biventricular pacing) has been demonstrated to improve HF symptoms and exercise tolerance and promote reverse remodeling. In patients with a QRS duration >120 m/s, ventricular dyssynchrony produces suboptimal ventricular filling, a reduction in contractility, paradoxical septal wall motion, and worsening MR. By activating both ventricles in a synchronized manner, CRT is able to increase LV filling time, decrease septal dyskinesis, and reduce MR. CRT is most applicable to patients with stage C–D HF with an EF ≤35% and a QRS duration ≥120 msec. However, studies have shown a survival benefit compared with an ICD even for patients in stage B (asymptomatic HF).[411]

5. An ICD is indicated in many patients with stage B–D HF because of the frequent association of a dilated dysfunctional ventricle with ventricular tachyarrhythmias. These may be placed transvenously or subcutaneously.[412]

a. Class I indications

- For primary prevention if EF ≤35% (NYHA class II–III) or EF ≤30% (NYHA class I) at least 40 days post MI or 90 days post revascularization on GDMT if anticipated survival >1 year
- For nonsustained VT due to prior MI, EF <40%, inducible VT/VF by EP study

b. Class IIa indication: patients with NYHA class IV symptoms who are candidates for a left ventricular assist device (LVAD) or transplantation[413]

6. Surgical ventricular restoration (SVR) can be used for patients who develop regional akinesia or dyskinesia subsequent to a single-territory MI and have class III–IV HF symptoms.[414] Combining a CABG with resection of nonfunctioning tissue to decrease ventricular size, restore geometry, and decrease wall stress should improve ventricular function. Cardiac MR is recommended to detect myocardial scar (LGE) and assess the function of remaining viable myocardium prior to considering SVR.

a. The LV end-systolic volume index (LVESVI) is a major determinant of survival in patients with ischemic cardiomyopathy. One study found that medical therapy, CABG, or mitral repair alone had limited benefit in patients with an LVESVI >60 mL/m^2.[415] However, in the STICH trial, a CABG + SVR was able to produce a reduction in LV volumes and a survival benefit if the initial LVESVI was <70 mL/m^2, although no improvement in symptoms or exercise tolerance was achieved.[416,417] Other studies reported a better reduction in LVESVI if a viable anterior wall could be revascularized,[418] with improved survival at follow-up if the residual LVESVI after SVR was <60 mL/m^2.[419]

b. In patients with large ventricular dimensions and moderate MR, CABG + SVR may reduce MR by reducing sphericity of the LV, thus reducing the longitudinal and transverse dimensions of the LV that increase the interpapillary muscle distance and cause apical tethering of the leaflets.[420] However, in patients with 3–4+ MR, mitral repair should be considered in addition to SVR, and has been shown to improve five-year survival.[414]

7. When the patient has advanced HF and is not a candidate for any of the above procedures, or remains severely symptomatic despite them, more advanced interventional therapy may be required.

a. Ventricular assist devices (VADs) have been recommended on an urgent basis for patients in INTERMACS class 1–2. However, the ROADMAP study suggested that survival was also improved with VADS for ambulatory patients in profile 3–4 compared with profiles 5–7.[404]

b. Cardiac transplantation should be considered in patients with advanced HF who have an EF <15% and a peak VO_2 <10–15 mL/min/m^2 with maximal exercise testing. Patients in lower INTERMACS categories can be managed medically until a transplant becomes available, but sicker patients may requiring bridging with a VAD.

c. VADs can be considered for destination therapy in patients who are not considered transplant candidates. The HeartMate III (Abbott) and HeartWare (Medtronic) systems are the most commonly used VADs for destination therapy.[421]

XV. Pericardial Disease

A. **Pathophysiology and diagnostic techniques.** The pericardium may become involved in a variety of systemic disease processes that produce either pericardial effusions or constriction. The most common causes of effusions are idiopathic (probably viral), postcardiotomy, malignant, uremic, pyogenic, and tuberculous. The most common causes of constriction are idiopathic or viral, postcardiotomy, radiation, and tuberculous. Early and late postoperative cardiac tamponade due to hemopericardium are discussed on pages 446–447 and 757–761.

1. Large effusions result in tamponade physiology with progressive low output states. They are best documented by 2D echocardiography, which delineates their size and provides hemodynamic evidence of tamponade.[422] Findings include:

a. RA and ventricular diastolic collapse

b. Exaggerated ventricular interdependence (enlarged RV and smaller LV dimensions during inspiration and vice versa during expiration with increased septal bounce toward the left during inspiration)

c. Abnormal respirophasic flow: a >20% reduction in mitral valve flow (peak E wave velocity) with inspiration and a >40% reduction in TV flow during expiration

d. Increased reversal of flow in the hepatic veins during atrial systole

e. A dilated IVC to >20 mm with lack of inspiratory collapse

f. Equilibration of intracardiac pressures (RVEDP = PCWP = LVEDP) by cardiac catheterization

2. Constriction can also produce a low output state despite preserved systolic function.

a. Cardiac catheterization will demonstrate a "square-root sign" in the RV tracing, indicating rapid early filling and a diastolic plateau caused by severe impairment to RV filling (Figure 1.32). There is equilibration of end-diastolic pressures and opposing changes in RV and LV filling during respiration.

b. Echocardiographic findings may mimic those of cardiac tamponade, but there is no respiratory variation of the dilated IVC.

c. Cardiovascular CT and MRI scanning can be done to assess the thickness of the pericardium, and MRI can identify pericardial inflammation.

d. The differentiation of constriction, which is surgically correctable, from restriction, which is not, can be difficult because they have many findings in common. Although restrictive pathology is associated with diastolic dysfunction, it may or

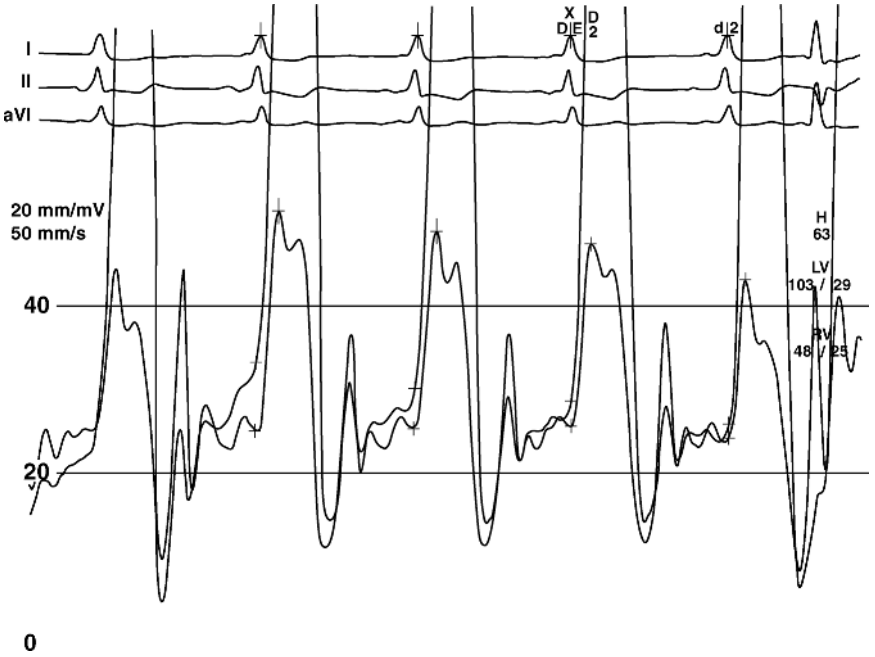


Figure 1.32 • Simultaneous right and left ventricular pressure tracings in constrictive pericarditis. Note the "dip-and-plateau" pattern as diastolic filling of the ventricular chambers is abruptly truncated by the constriction. Note also the equilibration of diastolic ventricular pressures. (Reproduced with permission from Myers et al., *Am Heart J* 1999;138:219–32.)

may not be associated with systolic dysfunction. However, the presence of significant PH suggests a restrictive process, since it is rarely seen with constriction. A number of echocardiographic methods are helpful in differentiating constriction from restriction, including septal bounce and respirophasic transvalvular flow variations, which are noted with constriction but not with restriction.[422–426]

B. Indications for surgery

1. Large effusions that fail to respond to noninvasive measures (dialysis for uremia, antibiotics for infection, radiation or chemotherapy for malignancy, thyroid replacement for myxedema) may be treated initially by a percutaneous drainage procedure (either pericardiocentesis with catheter drainage or balloon pericardiostomy).[427] Echocardiography is helpful in localizing the effusion and determining whether it is easily accessible to a percutaneous needle or not. Evidence of significant stranding of an effusion often suggests that percutaneous drainage will not be effective. If these procedures cannot be performed or the effusion recurs, surgical drainage should be performed.
2. Constriction that produces a refractory low output state, hepatomegaly, or peripheral edema should be treated by a pericardiectomy. Lesser degrees of constriction may resolve spontaneously or respond to a course of nonsteroidal anti-inflammatory medications or steroids.

C. Preoperative considerations

1. The subacute development of cardiac tamponade increases systemic venous pressures with eventual compromise in organ system perfusion from a low cardiac output syndrome. Patients frequently develop oliguric renal dysfunction, worsening respiratory status, and hepatic congestion. None of these will improve until drainage is accomplished. Fresh frozen plasma should be available if there is a pre-existing coagulopathy.
2. Both tamponade and constriction are associated with low cardiac output states. Intrinsic compensatory mechanisms to maintain blood pressure and cardiac output include a tachycardia and increased sympathetic tone. Maintenance of adequate preload is essential to increase cardiac output. β-blockers and vasodilators must be avoided. Patients with low output states from severe constriction may benefit from a few days of inotropic support prior to surgery. Patients with abnormal LV contractility and relaxation before surgery have a higher inotropic requirement after surgery with a higher mortality rate and worse long-term outcome. They might benefit the most from preoperative support.[428]
3. Preliminary pericardiocentesis for a very large effusion improves the safety of anesthetic induction, which can produce vasodilation, a fall in filling pressures, and profound hypotension.
4. Prepping and draping the patient prior to the induction of anesthesia may be a prudent maneuver in patients with an extremely tenuous hemodynamic status.

D. Surgical procedures

1. **Pericardial effusions.** If percutaneous drainage is inadequate or contraindicated, surgery should be performed.
   a. A subxiphoid pericardiostomy opens the pericardium, drains the pericardial space, allows for obtaining a small biopsy specimen, and obliterates the pericardial space by promoting the formation of adhesions with several days of chest

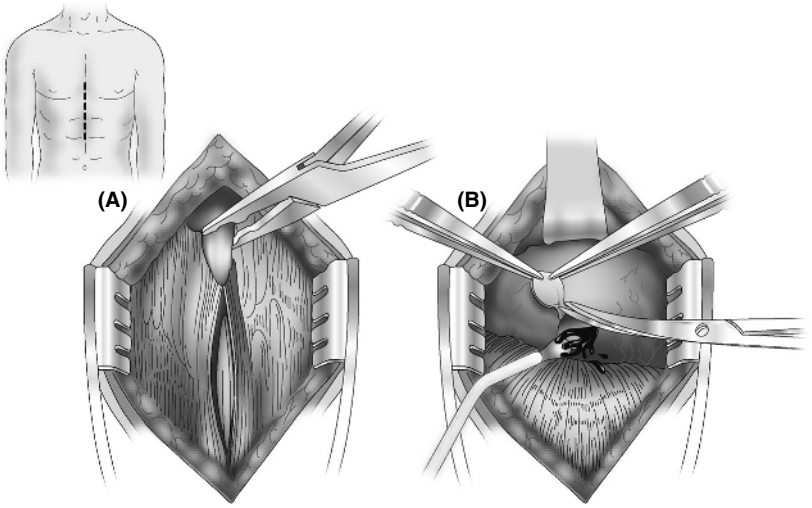


Figure 1.33 • The subxiphoid approach to pericardial disease. (A) An incision is made over the xiphisternal junction, extending inferiorly for 5 cm. The rectus fascia is incised and the xiphoid process is removed. (B) With upward traction on the distal sternum, the preperitoneal fat is swept away. The pericardium is grasped and incised and a small specimen may be removed. A finger is insinuated to break up any loculations, and pericardial fluid is aspirated with a suction catheter. A posterior chest tube is then placed below the heart.

tube drainage (Figure 1.33). It is the safest approach in the unstable patient and the best for patients with malignancies and a limited lifespan. Recurrence rate is lower with this procedure than with percutaneous catheter drainage.[429]

b. A pericardial window, created by a videothoracoscopic approach (VATS) or a limited thoracotomy, can be used to drain the effusion into the pleural space and obtain a biopsy specimen. These procedures require general anesthesia and are best utilized when there is suspicion of underlying pleuropulmonary pathology. One study suggested that a VATS approach produced a lower recurrence rate than a subxiphoid drainage procedure.[430]

2. Constrictive pericarditis

a. Pericardiectomy is best performed through a median sternotomy approach with pump standby, reserving a thoracotomy approach for cases of suspected infection. The pericardium is removed to within 2 cm of the phrenic nerves on either side, or at least as far as exposure allows. Dissection of the aorta and pulmonary arteries should be performed first, followed by the left and then the right ventricle to avoid pulmonary edema.

b. When the dissection plane between the thickened pericardium and the epicardium is difficult to achieve, the operation can be quite tedious. When dense calcific adhesions are present without a cleavage plane, use of CPB may allow for a safer dissection, although bleeding may be increased by heparinization. It is frequently prudent to leave heavily calcified areas adherent to the heart to minimize bleeding and pericardial damage.

c. Rarely, patients will develop epicardial constriction with a severe inflammatory response postoperatively, anecdotally noted in some patients with prior mediastinal radiation. This problem is approached using a "waffle" procedure, which entails multiple crisscrossing incisions in the scar tissue to optimize ventricular expansion and filling.

d. The operative mortality for pericardiectomies is 5–10%. Factors that compromise the long-term results of pericardiectomy include higher NYHA class, radiation-induced constriction, higher PA pressures, worse LV systolic function, and the presence of hyponatremia or renal dysfunction.[428,431]

XVI. Congenital Heart Disease: Atrial Septal Abnormalities

A. Pathophysiology

1. The atrial septum is composed embryologically of two separate septa which form a flap-like orifice that permits right-to-left blood flow as part of the fetal circulation. After birth, the septum seals, producing an intact atrial septum. In 25% of patients, it remains patent and is called a "patent foramen ovale" or PFO. The risk of a PFO is that of paradoxical embolism associated with right-to-left shunting when the RA pressure exceeds the LA pressure. This may be noted during straining, heavy lifting, and coughing, but can be present in more than half of patients at rest.

2. An atrial septal aneurysm (ASA) reflects redundant tissue in the area of the fossa ovalis that produces excessive mobility of the septum. This promotes adherence of platelet–fibrin debris to the left atrial side which can embolize into the systemic circulation, most commonly when there is a right-to-left shunt, which is present in 50–80% of patients with these aneurysms. The shunting may occur if there is a PFO or perforations developing within the aneurysm. Aneurysms are present in only 2% of patients with PFOs, but when present, the likelihood of sustaining a stroke is four times greater than with PFOs alone. Overall, PFOs are noted in 40% of patients with cryptogenic stroke, with 10% having both an ASA and a PFO.[432–434]

3. A small percentage of patients born with congenital atrial septal defects (ASDs) will reach adult life with a persistent left-to-right communication that may remain asymptomatic for decades. The increased shunt flow results in RA and RV enlargement, eventually leading to PH, AF, and TR. An untreated large ASD will eventually cause reversal of shunt flow, which is an inoperable situation.

B. Clinical presentation

1. **PFO.** Most patients with a PFO are asymptomatic. Clinical presentation is usually a transient ischemic attack (TIA) or stroke, or migraine-like headaches. In one study, a PFO and/or ASA could be identified in about 30% of patients <age 55 and 40% >age 55 who were diagnosed with a cryptogenic stroke.[435] Shunting through a PFO is believed to be the mechanism in platypnea–orthodeoxia syndrome (dyspnea and deoxygenation when sitting or standing up from a recumbent position).

2. **ASDs.** Depending on the size of the ASD, the degree of shunt flow, and the presence of partial anomalous pulmonary venous drainage (noted with sinus venosus defects), a patient may develop shortness of breath, fatigue, exercise

intolerance, frequent pulmonary infections, and palpitations from atrial arrhythmias. Although the flow is predominantly left-to-right, paradoxical embolism is noted in about 15% of patients.[436]

C. Evaluation

1. TEE with agitated saline injection should be performed in patients with cryptogenic stroke to detect right-to-left shunting through a PFO. A transcranial Doppler study with agitated saline is also helpful. Noninvasive lower-extremity venous studies tend to be negative because the embolus usually arises from the heart or consists of platelet-fibrin particles that are too small to detect.
2. **ASDs**. An echocardiogram can define the location and size of the septal defect, which can determine whether percutaneous closure is feasible. It should also quantitate the degree of left-to-right shunting, and assess RA and RV dilatation, RV dysfunction, and the degree of PH.

D. Indications for intervention

1. There is no indication for a prophylactic intervention in an asymptomatic patient with a PFO, because as an isolated entity, it is not an independent risk factor for stroke.[432]
2. There has been some interest in PFO closures in patients with migraine headaches and documented ischemic cerebral events.[437] However, a trial of patients undergoing percutaneous PFO closure for migraines failed to reach the study endpoint of a 50% reduction in migraine attacks.[438]
3. The optimal treatment for patients with a prior TIA or cryptogenic stroke associated with a PFO is controversial. Medical therapy with aspirin and/or warfarin can be recommended, because the risk of recurrent stroke is fairly low (about 2.5% at four years).[439] However, after several studies suggested that there was no benefit to PFO closure for secondary stroke prevention, a growing body of evidence suggested that use of a PFO percutaneous closure device, such as the Amplatzer PFO occluder device, is more efficacious than antiplatelet therapy in reducing the risk of subsequent stroke in selected patients.[434,439] One long-term follow-up study showed a 1% stroke rate out to 10 years.[440] Closure can be recommended for patients with coexistent PFO and ASA, in whom the risk of recurrent stroke is significantly greater (15% at four years).[441]
4. An ASD associated with symptoms, RA and RV enlargement (even if asymptomatic), or shunt flow exceeding 1.5:1 should be closed. Surgery can improve the patient's functional status with a reduction in RV volumes and pressures, although with no improvement in RV systolic function. ASD closure may also cause a slight reduction in LV volumes with an improvement in the LV EF. However, it has only a weak benefit in improving survival, and does not reduce the incidence of AF.[442] Patients over age 30–40 tend to have more preoperative AF and higher PA pressures, with the latter being predictive of late death from arrhythmias or HF.[443–445] An intervention can be offered as long as the PA pressure is less than 2/3 systemic or responds to vasodilators; irreversible PH contraindicates closure.

E. Interventions

1. Percutaneous closure can be performed for PFOs and secundum ASDs that are less than 38 mm in size and have a satisfactory tissue rim. Anticoagulation with antiplatelet therapy (aspirin +/– clopidogrel) is indicated for six months after placement of the device (Amplatzer).

2. Surgical closure, usually with a patch, is indicated in large secundum ASDs not amenable to percutaneous closure and for all nonsecundum ASDs, including sinus venosus defects close to the SVC with associated anomalous pulmonary venous drainage, and ostium primum defects. This can frequently be done through a right minithoracotomy incision.[446]

XVII. Adults with Other Congenital Heart Disease

For the management of adults with all other forms of congenital heart disease, the reader is referred to the ACC/AHA guidelines available at www.acc.org.[447]

References

1. Arnett DK, Blumenthal RS, Albert MA, et al. ACC/AHA guideline on the primary prevention of cardiovascular disease: executive summary: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines. *J Am Coll Cardiol* 2019;74:1376–414.
2. Boden WE, O'Rourke RA, Teo KK. Optimal medical therapy with or without PCI for stable coronary disease. *N Engl J Med* 2007;356:1503–16.
3. De Bruyne B, Fearon WF, Pijls NHJ. Fractional flow reserve-guided PCI for stable coronary artery disease. *N Engl J Med* 2014;371:1208–17.
4. Gotberg M, Christiansen EH, Gudmundsdottir IJ, et al. Instantaneous wave-free ratio versus fractional flow reserve to guide PCI. *N Engl J Med* 2017;376:1813–23.
5. Hillis LD, Smith PK, Anderson JL. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery. *J Am Coll Cardiol* 2011;58:e123–210.
6. Weiss S, Weintraub W. Revascularization vs. medical therapy in stable ischemic heart disease. *Prog Cardiovasc Dis* 2015;58:299–305.
7. Patel MR, Calhoon JH, Dehmer JH, Grantham JA, Maddox TM, Maron DJ, Smith PK. ACC/AATS/AHA/ASE/ASNC/SCAI/SCCT/STS 2017 appropriate use criteria for coronary revascularization in patients with stable ischemic heart disease. *J Am Coll Cardiol* 2017;69:2212–41.
8. Mohr FW, Morice MC, Kappetein AP, et al. Coronary artery bypass graft surgery versus percutaneous intervention in patients with three-vessel disease and left main disease: 5-year follow-up of the randomized clinical SYNTAX trial. *Lancet* 2013;381:629–38.
9. Mack M, Baumgarten H, Lytle BS. Why surgery won the SYNTAX trial and why it matters. *J Thorac Cardiovasc Surg* 2016;152:1237–40.
10. Farkouh ME, Domanski M, Dangas GD, et al. on behalf of the FREEDOM follow-on study investigators. Long-term survival following multivessel revascularization in patients with diabetes (FREEDOM follow-on study). *J Am Coll Cardiol* 2019;73:629–38.
11. Farkouh ME, Domanski M, Sleeper LA, et al. Strategies for multivessel revascularization in patients with diabetes. *N Engl J Med* 2012;367:2375–84.
12. Esper RB, Farkouh ME, Riberio EE, et al. SYNTAX score in patients with diabetes undergoing coronary revascularization in the FREEDOM trial. *J Am Coll Cardiol* 2018;72:2826–37.
13. Généreux P, Palmerini T, Caixeta A. Quantification and impact of untreated coronary artery disease after percutaneous coronary intervention: the residual SYNTAX (Synergy Between PCI with Taxus and Cardiac Surgery) score. *J Am Coll Cardiol* 2012;59:2165–74.
14. Milojevic M, Head SJ, Parasca CA, et al. Causes of death following PCI versus CABG in complex CAD: 5-year follow-up of SYNTAX. *J Am Coll Cardiol* 2016;67:42–55.
15. Farooq V, van Klaveren D, Steyerberg EW, et al. Anatomical and clinical characteristics to guide decision making between coronary artery bypass surgery and percutaneous coronary intervention for individual patients: development and validation of SYNTAX score II. *Lancet* 2013;381:639–50.
16. Dangas GD, Farkouh ME, Sleeper LA, et al. Long-term outcome of PCI versus CABG in insulin and non-insulin treated diabetic patients: results from the FREEDOM trial. *J Am Coll Cardiol* 2014;64:1189–97.
17. Doenst T, Haverich A, Serruys P, et al. PCI and CABG for treating stable coronary artery disease. *J Am Coll Cardiol* 2019;73:964–76.

18. Velaquez EJ, Lee KL, Deja MA, et al. for the STICH investigators. Coronary-artery bypass surgery in patients with left ventricular dysfunction. *N Engl J Med* 2011;364:1607–16.
19. Michler RE. A decade after the Surgical Treatment for Ischemic Heart Failure (STICH) trial: weaving firm clinical recommendations from lessons learned. *J Thorac Cardiovasc Surg* 2019;157:950–7.
20. Bonow RO, Maurer G, Lee KL, et al. Myocardial viability and survival in ischemic left ventricular dysfunction. *N Engl J Med* 2011;364:1617–25.
21. Allman KC, Shaw LJ, Hachamovitch R, Udelson JE. Myocardial viability testing and impact of revascularization on prognosis in patients with coronary artery disease and left ventricular dysfunction: a meta-analysis. *J Am Coll Cardiol* 2002;39:1151–8.
22. Nagendran J, Bozso SJ, Norris CM, et al. Coronary artery bypass surgery improves outcomes in patients with diabetes and left ventricular dysfunction. *J Am Coll Cardiol* 2018;71:819–27.
23. Amsterdam EA, Wenger NK, Brindis RG, et al. 2014 AHA/ACC guideline for the management of patients with non-ST-elevation acute coronary syndromes. *Circulation* 2014;130:3349–426.
24. Anderson JL, Morrow DA. Acute myocardial infarction. *N Eng J Med* 2017;376:2053–64.
25. Hoedemaker NPG, Damman P, Woudstra P, et al. Early invasive versus selective strategy for non-ST-segment elevation acute coronary syndrome: the ICTUS trial. *J Am Coll Cadiol* 2017;69:1883–93.
26. Patel MR, Calhoon JH, Dehmer JH, Grantham JA, Maddox TM, Maron DJ, Smith PK. l: ACC/AATS/AHA/ASE/ASNC/SCAI/SCCT/STS: 2016 appropriate use criteria for coronary revascularization in patients with acute coronary syndromes. *J Am Coll Cardiol* 2017;69:570–91.
27. Hu Y, Zhiping L, Chen J, Shen C, Song Y, Zhong Q. The effect of the time interval between coronary angiography and on-pump cardiac surgery on risk of postoperative acute kidney injury: a meta-analysis. *J Cardiothorac Surg* 2013;8:178.
28. Kwak YL, Kim JC, Choi YS, Yoo KJ, Song Y, Shim JK. Clopidogrel responsiveness regardless of the discontinuation date predicts increased blood loss and transfusion requirement after off-pump coronary artery bypass graft surgery. *J Am Coll Cardiol* 2010;56:1994–2002.
29. Mahla E, Suarez TA, Bliden KP, et al. Platelet function measurement-based strategy to reduce bleeding and waiting time in clopidogrel-treated patients undergoing coronary artery bypass graft surgery: the timing based on platelet function strategy to reduce clopidogrel-associated bleeding related to CABG (TARGET-CABG) Study. *Circ Cardiovasc Interv* 2012;5:261–9.
30. Basir MB, Schreiber T, Grines CL, et al. Effect of early initiation of mechanical circulatory support on survival in cardiogenic shock. *Am J Cardiol* 2017;119:845–51.
31. Flaherty MP, Khan AR, O'Neill WW. Early initiation of Impella in acute myocardial infarction complicated by cardiogenic shock improves survival: a meta-analysis. *JACC Cardiovasc Interv* 2017;10:1805–6.
32. McCann GP, Khan JN, Greenwood JP, et al. Complete versus lesion-only primary PCI. The Cardiovascular MR CvLPRIT Substudy. *J Am Coll Cardiol* 2015;66:2713–24.
33. Thiele H, Akin I, Sandri S, et al. One-year outcomes after PCI strategies in cardiogenic shock. *N Engl J Med* 2018;379:1699–710.
34. Caceres M, Weiman DS. Optimal timing of coronary artery bypass grafting in acute myocardial infarction. *Ann Thorac Surg* 2013;95:365–72.
35. Acharya D, Gulack BC, Loyaga-Rendon RY, et al. Clinical characteristics and outcome of patients with myocardial infarction and cardiogenic shock undergoing coronary artery bypass surgery: data from The Society of Thoracic Surgeons national database. *Ann Thorac Surg* 2016;101:558–66.
36. Dangas GD, Kini AS, Sharma SK, et al. Impact of hemodynamic support with Impella 2.5 versus intra-aortic balloon pump on prognostically important clinical outcomes in patients undergoing high-risk percutaneous coronary intervention (from the PROTECT II randomized trial). *Am J Cardiol* 2014;113:222–8.
37. Tonino PA, De Bruyne B, Piljls NH, et al. Fractional flow reserve versus angiography for guiding percutaneous coronary intervention. *N Eng J Med* 2009;360:213–24.
38. Shah T, Geleris JD, Zhong M, Swaminathan R, Kim LK, Feldman DN. Fractional flow reserve to guide surgical coronary revascularization. *J Thorac Dis* 2017;9 (Suppl 4): S317–26.
39. Toth G, De Bruyne B, Casselman F, et al. Fractional flow reserve-guided versus angiography-guided coronary artery bypass graft surgery. *Circulation* 2013;128:1405–11.

40. Fournier S, Toth GG, De Bruyne B, et al. Six-year follow-up of fractional flow reserve-guided versus angiography-guided coronary artery bypass graft surgery. *Circ Cardiovasc Interv* 2018;11:e06368.
41. Mahmoud AN, Shah NH, Elgendy IY, et al. Safety and efficacy of second-generation drug-eluting stents compared with bare-metal stents: an updated meta-analysis and regression of 9 randomized clinical trials. *Clin Cardiol* 2018;41:151–8.
42. Ng VG, Lansky AJ. Platelet function testing: a research tool with limited clinical utility. www.acc.org/latest-in-cardiology/articles/2016/05/10/07/22.
43. Misumida N, Abo-Aly M, Kim SM, Ogunbayo GO, Abdel-Latif A, Ziada KM. Efficacy and safety of short-term dual antiplatelet therapy (≤6 months) after percutaneous coronary intervention for acute coronary syndrome: a systematic review and meta-analysis of randomized controlled trials. *Clin Cardiol* 2018;41:1455–62.
44. Puskas JD, Halkos ME, DeRose JJ, et al. Hybrid coronary revascularization for the treatment of multivessel coronary artery disease: a multicenter observational study. *J Am Coll Cardiol* 2016;68:356–65.
45. Rosenblum JM, Harskamp RE, Hoedemaker N, et al. Hybrid coronary revascularization versus coronary artery bypass surgery with bilateral or single internal mammary artery grafts. *J Thorac Cardiovasc Surg* 2016;151:1081–9.
46. Xia Y, Katz AN, Forest SJ, Pyo RT, Greenberg MA, DeRose JJ Jr. Hybrid coronary revascularization has improved short-term outcomes but worse mid-term reintervention rates compared to CABG: a propensity matched analysis. *Innovations (Phila)* 2017;12:174–9.
47. Thaper A, Kulik A. Rationale for administering beta-blocker therapy to patients undergoing coronary artery bypass surgery: a systematic review. *Expert Opin Drug Saf* 2018;17:805–13.
48. Brinkman W, Herbert MA, O'Brien S, et al. Preoperative ß-blocker use in coronary artery bypass grafting surgery: national database analysis. *JAMA Intern Med* 2014;174:1320–7.
49. Doherty JU, Gluckman TJ, Hucker WJ, et al. 2017 ACC Expert consensus decision pathway for periprocedural management of anticoagulation in patients with nonvalvular atrial fibrillation. *J Am Coll Cardiol* 2017;69:871–92.
50. Renda G, Ricci F, Giugliano RP, De Caterina R. Non-vitamin K antagonist oral anticoagulants in patients with atrial fibrillation and valvular heart disease. *J Am Coll Cardiol* 2017;69:1363–71.
51. Hassan K, Bayer N, Schlingloff F, et al. Bleeding complications after use of novel oral anticoagulants in patients undergoing cardiac surgery. *Ann Thorac Surg* 2018;105:702–8.
52. Aboul-Hassan SS, Stankowski T, Marczak J, et al. The use of preoperative aspirin in cardiac surgery: a systematic review and meta-analysis. *J Card Surg* 2017;32:758–74.
53. Hastings S, Myles PA, McIlroy DM. Aspirin and coronary artery surgery: an updated meta-analysis. *Br J Anaesth* 2016;116:716–7.
54. Myles PS, Smith JA, Forbes A, et al. Stopping vs. continuing aspirin before coronary artery surgery. *N Engl J Med* 2016;374:728–37.
55. Ferraris VA, Saha SP, Oestreich JH, et al. 2012 Update to The Society of Thoracic Surgeons guideline on use of antiplatelet drugs in patients having cardiac and noncardiac operations. *Ann Thorac Surg* 2012;94:1761–81.
56. Maltais S, Perrault LP, Do QB. Effect of clopidogrel on bleeding and transfusions after off-pump coronary artery bypass graft surgery: impact of discontinuation prior to surgery. *Eur J Cardiothorac Surg* 2008;34:127–31.
57. Angiolillo DJ, Firstenberg MS, Price MJ, et al. Bridging antiplatelet therapy with cangrelor in patients undergoing cardiac surgery: a randomized controlled trial. *JAMA* 2012;307:265–74.
58. Stucchi M, Cantoni S, Piccinelli E, Savonitto S, Morici N. Anemia and acute coronary syndrome: current perspectives. *Vasc Health Risk Manag* 2017;14:109–18.
59. Carson JL, Stanworth SJ, Alexander JH, et al. Clinical trials evaluating red blood cell transfusion thresholds: an updated systematic review and with additional focus on patients with cardiovascular disease. *Am Heart J* 2018;200:96–101.
60. Williams ML, Rankin JS, Slaughter MS, Gammie JS. Preoperative hematocrit is a powerful predictor of adverse outcomes in coronary artery bypass graft surgery: a report from the Society of Thoracic Surgeons adult cardiac surgery database. *Ann Thor Surg* 2013;96:1628–34.
61. LaPar DJ, Hawkins RB, McMurry TL, et al. Preoperative anemia versus blood transfusion: which is the culprit for worse outcomes in cardiac surgery? *J Thorac Cardiovasc Surg* 2018;156:66–74.

62. Bagshaw SM, Galbraith PD, Mitchell LB, Suave R, Exner DV, Shali WA. Prophylactic amiodarone for prevention of atrial fibrillation after cardiac surgery: a meta-analysis. *Ann Thorac Surg* 2006;82:1927–37.
63. Liaopoulos OJ, Choi YH, Kuhn EW, et al. Statins for prevention of atrial fibrillation after cardiac surgery: a systematic literature review. *J Thorac Cardiovasc Surg* 2009;138:678–86.
64. Curtis M, Deng Y, Lee VV, et al. Effect of dose and timing of preoperative statins on mortality after coronary artery bypass surgery. *Ann Thorac Surg* 2017;104:782–9.
65. Katznelson R, Djaiani GN, Borger MA, et al. Preoperative use of statins is associated with reduced early delirium rates after cardiac surgery. *Anesthesiology* 2009;110:67–73.
66. Wang J, Gu C, Gao M, Yu W, Yu Y. Preoperative statin therapy and renal outcomes after cardiac surgery: a meta-analysis and meta-regression of 59,771 patients. *Can J Cardiol* 2015;31:1051–60.
67. Whitlock RP, Chan S, Devereaux PJ, et al. Clinical benefit of steroid use in patients undergoing cardiopulmonary bypass: a meta-analysis of randomized trials. *Eur Heart J* 2008;29:2592–600.
68. Rousou LJ, Taylor KB, Lu XG, et al. Saphenous vein conduits harvested by endoscopic technique exhibit structural and functional damage. *Ann Thorac Surg* 2009;87:62–70.
69. Kroeze VJ, Lam KY, van Straten AHM, Houterman S, Soliman-Hamad, MA. Benefits of endoscopic vein harvesting in coronary artery bypass grafting. *Ann Thorac Surg* 2019;108:1793–800.
70. Zenati MA, Bhatt DL, Bakaeen FG, et al. Randomized trial of endoscopic or open-vein harvesting for coronary-artery bypass. *N Engl J Med* 2019;380:132–41.
71. Aldea GS, Bakaeen FG, Pal J, et al. The Society of Thoracic Surgeons Clinical Practice Guidelines on arterial conduits for coronary artery bypass grafting. *Ann Thorac Surg* 2016;101:801–9.
72. Gaudino M, Taggart D, Suma H, Puskas JD, Crea F, Massetti M. The choice of conduits in coronary artery bypass surgery. *J Am Coll Cardiol* 2015;66:1729–37.
73. Samadashvili Z, Sundt TM III, Wechsler A, et al. Multiple versus single arterial coronary bypass graft surgery for multivessel disease. *J Am Coll Cardiol* 2019;74:1275–85.
74. Yoshizaki T, Tabuchi N, Toyama M. Verapamil and nitroglycerin improves the patency rate of radial artery grafts. *Asian Cardiovasc Thorac Ann* 2008;16:396–400.
75. He GW, Taggart DP. Antispastic management in arterial grafts in coronary artery bypass grafting surgery. *Ann Thorac Surg* 2016;102:659–68.
76. Puskas KD, Stringer A, Hwang SN, et al. Neurocognitive and neuroanatomic changes after off-pump versus on-pump coronary artery bypass grafting: long-term follow-up of a randomized trial. *J Thorac Cardiovasc Surg* 2011;141:1116–27.
77. Shroyer AL, Hattler B, Wagner TH, et al. Five-year outcomes after on-pump and off-pump coronary-artery bypass. *N Engl J Med* 2017;377:623–32.
78. Smart NA, Dieberg G, King N. Long-term outcomes of on- versus off-pump coronary artery bypass grafting. *J Am Coll Cardiol* 2018;71:983–91.
79. Chikwe J, Lee T, Itagaki S, Adams DH, Egorova NN. Long-term outcomes after off-pump versus on-pump coronary artery bypass grafting by experienced surgeons. *J Am Coll Cardiol* 2018;72:1478–86.
80. Fattouch K, Guccione F, Dioguardi P, et al. Off-pump versus on-pump myocardial revascularization in patients with ST-segment myocardial infarction: a randomized trial. *J Thorac Cardiovasc Surg* 2009;137:650–7.
81. Kikuchi K, Mori M. Minimally invasive coronary artery bypass grafting: a systematic review. *Asian Cardiovasc Thorac Ann* 2017;25:364–70.
82. Kikchi K, Chen X, Mori M, Kurata A, Tao L. Perioperative outcomes of off-pump minimally invasive coronary artery bypass grafting with bilateral internal thoracic arteries under direct vision. *Interact Cardiovasc Thorac Surg* 2017;24:696–701.
83. Deppe AC, Liakopoulos OJ, Kuhn EW, et al. Minimally invasive direct coronary bypass grafting versus percutaneous intervention for single-vessel disease: a meta-analysis of 2885 patients. *Eur J Cardiothorac Surg* 2015;47:397–406.
84. Kofler M, Stastny L, Reinstadler SJ, et al. Robotic versus conventional coronary artery bypass grafting: direct comparison of long-term clinical outcome. *Innovations (Phila)* 2017;12:239–46.
85. Allen KB, Dowling RD, Angell WW, et al. Transmyocardial revascularization: 5 year follow-up of a prospective, randomized multicenter trial. *Ann Thorac Surg* 2004;77:1228–34.

86. Aaberge L, Rootwelt K, Blomhoff S, Saatvedt K, Abdelnoor M, Forfang K. Continued symptomatic improvement three to five years after transmyocardial revascularization with CO(2) laser: late clinical follow-up of the Norwegian randomized trial with transmyocardial revascularization. *J Am Coll Cardiol* 2002;39:1588–93.
87. Allen GS. Mid-term results after thoracoscopic transmyocardial laser revascularization. *Ann Thorac Surg* 2005;80:553–8.
88. Heatlie GJ, Mohiaddin R. Left ventricular aneurysm: comprehensive assessment of morphology, structure and thrombus using cardiovascular magnetic resonance. *Clin Radiol* 2005;60:687–92.
89. Lapeyre AC 3rd, Steele PM, Kazmier FJ, Chesebro JH, Vlietstra RE, Fuster V. Systemic embolism in chronic left ventricular aneurysm: incidence of and the role of anticoagulation. *J Am Coll Cardiol* 1985;6:534–8.
90. Doss N, Martens S, Sayour S, Hemmer W. Long term follow up of left ventricular function after repair of left ventricular aneurysm: a comparison of linear closure versus patch plasty. *Eur J Cardiothorac Surg* 2001;20:783–5.
91. Shapira OM, Davidoff R, Hilkert RJ, Aldea GS, Fitzgerald CA, Shemin RJ. Repair of left ventricular aneurysm: long-term results of linear repair versus endoaneurysmorrhaphy. *Ann Thorac Surg* 1997;63:701–5.
92. Dor V, Di Donato M, Sabatier M, Montiglio F, Civaia F, RESTORE Group. Left ventricular reconstruction by endoventricular circular patch plasty repair: a 17-year experience. *Semin Thorac Cardiovasc Surg* 2001;13:435–7.
93. Athanasuleas C, Buckberg GD, Stanley AW, et al. Surgical ventricular restoration in the treatment of congestive heart failure due to post-infarction ventricular dilatation. *J Am Coll Cardiol* 2004;44:1439–45.
94. Di Donato M, Castelvecchio S, Kukulski T, et al. Surgical ventricular restoration: left ventricular shape influence on cardiac function, clinical status, and survival. *Ann Thorac Surg* 2009;87:455–62.
95. Dzemali O, Risteski P, Bakhtiary F, et al. Surgical ventricular remodeling leads to better long-term survival and exercise tolerance than coronary artery bypass grafting alone in patients with moderate ischemic cardiomyopathy. *J Thorac Cardiovasc Surg* 2009;138:663–8.
96. Di Donato M, Sabatier N, Dor V, Toso A, Maioli M, Fantini F. Akinetic versus dyskinetic postinfarction scar: relation to surgical outcome in patients undergoing endoventricular circular patch plasty repair. *J Am Coll Cardiol* 1997;29:1569–75.
97. Jones RH, Velazquez EJ, Michler RE, et al. Coronary bypass surgery with or without surgical ventricular reconstruction. *N Engl J Med* 2009;360:1705–17.
98. Dor V, Sabatier M, Montiglio F, et al. Results of nonguided subtotal endocardiectomy associated with left ventricular reconstruction in patients with ischemic ventricular arrhythmias. *J Thorac Cardiovasc Surg* 1994;107:1301–7.
99. Sosa E, Jatene A, Kaeriyama JV, et al. Recurrent ventricular tachycardia associated with post infarction aneurysm: results of left ventricular reconstruction. *J Thorac Cardiovasc Surg* 1992;103:855–60.
100. Birnbaum Y, Fishbein MC, Blanche C, Siegel RJ. Ventricular septal rupture after acute myocardial infarction. *N Engl J Med* 2002;347:1426–32.
101. Arnaoutakis GJ, Zhao Y, George TJ, Sciortino CM, McCarthy PM, Conte JV. Surgical repair of ventricular septal defect after myocardial infarction: outcomes from The Society of Thoracic Surgeons national database. *Ann Thorac Surg* 2012;94:436–44.
102. Lundblad R, Abdelnoor M, Geiran OR, Svennevig JL. Surgical repair of postinfarction ventricular septal rupture: risk factors of early and late death. *J Thorac Cardiovasc Surg* 2009;137:862–8.
103. David TE, Armstrong S. Surgical repair of postinfarction ventricular septal defect by infarct exclusion. *Semin Thorac Cardiovasc Surg* 1998;10:105–10.
104. Muehrcke DD, Daggett WM Jr, Buckley MJ, Akins CW, Hilgenberg AD, Austen WG. Postinfarct ventricular septal defect repair: effect of coronary artery bypass grafting. *Ann Thorac Surg* 1992;54:876–83.
105. Sabiniewicz R, Huczek Z, Zbronski K, et al. Percutaneous closure of post-infarction ventricular septal defects: an over decade-long experience. *J Interv Cardiol* 2017;30:63–71.
106. Bonow RO, Carabello BA, Chatterjee K, et al. 2008 focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American

College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing committee to revise the 1998 guidelines for the management of patients with valvular heart disease): endorsed by the Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. *J Am Coll Cardiol* 2008;52:1–142.

107. Nishimura, RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC Guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation* 2014;129:e521–643.
108. Yan AT, Koh M, Chan KK, et al. Association between cardiovascular risk factors and aortic stenosis: the CANHEART aortic stenosis study. *J Am Coll Cardiol* 2017;69:1523–32.
109. Rossebø AB, Pedersen TR, Boman K, et al. Intensive lipid lowering with simvastatin and ezetimibe in aortic stenosis. *N Engl J Med* 2008;359:1343–56.
110. Bartunek J, Sys SU, Rodrigues AC, Schuerbeeck EV, Mortier L, de Bruyne B. Abnormal systolic intracavity flow velocities after valve replacement for aortic stenosis: mechanisms, predictive factors, and prognostic significance. *Circulation* 1996;93:712–9.
111. Omran H, Schmidt H, Hackenbroch M, et al. Silent and apparent cerebral embolism after retrograde catheterisation of the aortic valve in valvular stenosis: a prospective, randomised study. *Lancet* 2003;361:1241–6.
112. Pibarot P, Dumesnil JG. Paradoxical low-flow, low-gradient aortic stenosis: new evidence, more questions. *Circulation* 2013;128:1729–32.
113. Pibarot P, Clavel MA. Management of paradoxical low-flow, low-gradient aortic stenosis: need for an integrated approach, including assessment of symptoms, hypertension, and stenosis severity. *J Am Coll Cardiol* 2015;65:67–71.
114. Eleid MF, Sorajja P, Michelena HI, Malouf JF, Scott CG, Pellikka PA. Flow-gradient patterns in severe aortic stenosis with preserved ejection fraction: clinical characteristics and predictors of survival. *Circulation.*2013;128:1781–9.
115. Dumesnil JG, Pibarot P, Carabello B. Paradoxical low flow and/or low gradient severe aortic stenosis despite preserved left ventricular ejection fraction: implications for diagnosis and treatment. *Eur Heart J* 2010;31:281–9.
116. Ozkan A, Hachamovitch R, Kapadia SR, Tuzcu EM, Marwick TH. Impact of aortic valve replacement on outcome of symptomatic patients with severe aortic stenosis with low gradient and preserved left ventricular ejection fraction. *Circulation* 2013;128:622–31.
117. Pawade T, Clavel MA, Tribouilloy C, et al. Computed tomography aortic valve calcium scoring in patients with aortic stenosis. *Circ Cardiovasc Imaging* 2018;111:e007146.
118. Clavel MA, Burwash IG, Pibarot P. Cardiac imaging for assessing low-gradient severe aortic stenosis. *JACC Cardiovasc Imaging* 2017;10:185–202.
119. Clavel MA, Pibarot P, Messika-Zeitoun D, et al. Impact of aortic valve calcification, as measured by MDCT, on survival in patients with aortic stenosis: results of an international registry study. *J Am Coll Cardiol* 2014;64:1202–13.
120. Rafique AM, Biner S, Ray I, et al. Meta-analysis of prognostic value of stress testing in patients with asymptomatic aortic stenosis. *Am J Cardiol* 2009;104:972–7.
121. Magne J, Lancelotti P, Piérard LA. Exercise testing in asymptomatic aortic stenosis. *JACC Cardiovasc Imaging* 2014;7:188–99.
122. van Gils L, Clavel MA, Vollema EM, et al. Prognostic implications of moderate aortic stenosis in patients with left ventricular systolic dysfunction. *J Am Coll Cardiol* 2017;69:2383–92.
123. Pellikka PA, Nishimura RA, Bailey KR, Tajik AJ. The natural history of adults with asymptomatic, hemodynamically significant aortic stenosis. *J Am Coll Cardiol* 1990;15:1012–7.
124. Pellikka PA, Sarano ME, Nishimura RA, et al. Outcome of 622 adults with asymptomatic, hemodynamically significant aortic stenosis during prolonged follow-up. *Circulation* 2005;111:3290–5.
125. Henkel DM, Malouf JF, Connolly HM, et al. Asymptomatic left ventricular systolic dysfunction in patients with severe aortic stenosis. *J Am Coll Cardiol* 2012;60:2325–9.
126. Nakatsuma K, Taniguchi T, Morimoto T, et al. B-type natriuretic peptide in patients with asymptomatic severe aortic stenosis. *Heart* 2019;105:384–90.
127. Horstkotte D, Loogen F. The natural history of aortic valve stenosis. *Eur Heart J* 1988;9(Suppl E): 57–64.

128. Leon MB, Smith CR, Mack M, et al. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med* 2010;36:1597–607.
129. Glaser N, Persson M, Jackson V, Holzmann MJH, Franco-Cereceda A, Sartipy U. Loss in life expectancy after surgical aortic valve replacement: SWEDEHEART study. *J Am Coll Cardiol* 2019;74:26–33.
130. Shirai S, Taniguchi T, Morimoto T, et al. Five-year clinical outcome of asymptomatic vs. symptomatic severe aortic stenosis after aortic valve replacement. *Circ J* 2017;81:485–94.
131. Levy F, Laurent M, Monin JL, et al. Aortic valve replacement for low-flow/low-gradient aortic stenosis: operative risk stratification and long-term outcome: a European Multicenter study. *J Am Coll Cardiol* 2008;51:1466–72.
132. Tribouilloy C, Lévy F, Rusinaru D, et al. Outcome after aortic valve replacement for low-flow/low-gradient aortic stenosis without contractile reserve on dobutamine stress echocardiography. *J Am Coll Cardiol* 2009;53:1865–73.
133. Maes F, Lerakis S, Barbosa Ribeiro H, et al. Outcomes from transcatheter aortic valve replacement in patients with low-flow, low-gradient aortic stenosis and left ventricular ejection fraction less than 30%: a substudy from the TOPAS-TAVI Registry. *JAMA Cardiol* 2018;4:64–70.
134. Bergler-Klein J, Mundigler G, Pibarot P, et al. B-type natriuretic peptide in low-flow, low-gradient aortic stenosis: relationship to hemodynamics and clinical outcome: results from the Multicenter Truly or Pseudo-Severe Aortic Stenosis (TOPAS) study. *Circulation* 2007;115:2848–55.
135. Annabi MS, Touboul E, Dahuo A, et al. Dobutamine stress echocardiography for management of low-flow, low-gradient aortic stenosis. *J Am Coll Cardiol* 2018;71:475–85.
136. Clavel MA, Ennezat PV, Marechaux S, et al. Stress echocardiography to assess stenosis severity and predict outcome in patients with paradoxical low-flow, low-gradient aortic stenosis and preserved LVEF. *JACC Cardiovasc Imaging* 2013;6:175–83.
137. Hachicha Z, Dumesnil JG, Bogaty P, Pibarot P. Paradoxical low-flow, low-gradient severe aortic stenosis despite preserved ejection fraction is associated with higher afterload and reduced survival. *Circulation* 2007;115:2856–64.
138. Herrmann HC, Pibarot T, Hueter I, et al. Predictors of mortality and outcomes of therapy in low-flow severe aortic stenosis: a Placement of Aortic Transcatheter Valves (PARTNER) trial analysis. *Circulation* 2013;127:2316–26.
139. Pai RG, Varadarajan P, Razzouk A. Survival benefit of aortic valve replacement in patients with severe aortic stenosis with low ejection fraction and low gradient with normal ejection fraction. *Ann Thorac Surg* 2008;86:1781–90.
140. Tribouilloy C, Rusinaru D, Marechaux S, et al. Low-gradient, low-flow severe aortic stenosis with preserved left ventricular ejection fraction: characteristics, outcome, and implications for surgery. *J Am Coll Cardiol* 2015;65:55–66.
141. Bonow RO, Brown AS, Gillam LD, Kapadia SR, Kavinsky CJ, Lindman BR, Mack MJ, Thourani VH. ACC/AATS/AHA/ASE/EACTS/HVS/SCA/SCAI/SCCT/SCMR/STS 2017 Appropriate Use Criteria for the Treatment of Patients With Severe Aortic Stenosis. A Report of the American College of Cardiology Appropriate Use Criteria Task Force, American Association for Thoracic Surgery, American Heart Association, American Society of Echocardiography, European Association for Cardio-Thoracic Surgery, Heart Valve Society, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, and Society of Thoracic Surgeons. *J Am Coll Cardiol* 2017;70:2566–92 and doi: 10.1016/j.jacc.2017.09.018
142. Mack MJ, Leon MB, Thourani V, et al. Transcatheter aortic-valve replacement with a balloon expandable valve in low-risk patients. *N Engl J Med* 2019;380:1695–705.
143. Clavel MA, Webb JG, Pibarot P, et al. Comparison of the hemodynamic performance of percutaneous and surgical bioprostheses for the treatment of severe aortic stenosis. *J Am Coll Cardiol* 2009;53:1883–91.
144. Blackman DJ, Saraf S, MacCarthy PA, et al. Long-term durability of transcatheter aortic valve prostheses. *J Am Coll Cardiol* 2019;73:537–45.
145. Vincentelli A, Sisen S, Le Tourneau T, et al. Acquired von Willebrand syndrome in aortic stenosis. *N Engl J Med* 2003;349:343–9.
146. Van Belle E, Vincent F, Rauch A, et al. von Willebrand factor and management of heart valve disease. *J Am Coll Cardiol* 2019;73:1078–88.

147. Blackshear JL, McRee CW, Safford R, et al. von Willebrand factor abnormalities and Heyde syndrome in dysfunctional heart valve prostheses. *JAMA Cardiol* 2016;1:198–204.
148. Steinlechner B, Zeidler P, Base E, et al. Patients with severe aortic valve stenosis and impaired platelet function benefit from preoperative desmopressin infusion. *Ann Thorac Surg* 2011;91:1420–6.
149. Smith MM, Barbara DW, Mauermann WJ, Viozzi CF, Dearani JA, Grim KJ. Morbidity and mortality associated with dental extraction before cardiac operation. *Ann Thorac Surg* 2014;97:838–44.
150. Allen KB, Chhatriwalla AK, Cohen DJ, et al. Bioprosthetic valve fracture to facilitate transcatheter valve-in-valve implantation. *Ann Thorac Surg* 2017;104:1501–8.
151. Salenger R, Gammie JS, Collins JA. Minimally invasive aortic valve replacement. *J Card Surg* 2015;31:38–50.
152. Glauber M, Miceli A, Gilmanov D, et al. Right anterior minithoracotomy versus conventional aortic valve replacement: a propensity score matched study. *J Thorac Cardiovasc Surg* 2013;145:1222–6.
153. Stoliński J, Plicner D, Grudzień G, et al. A comparison of minimally invasive and standard aortic valve replacement. *J Thorac Cardiovasc Surg* 2016;152:1030–9.
154. Ensminger S, Fujita B, Bauer T, et al. Rapid deployment versus conventional bioprosthetic valve replacement for aortic stenosis. *J Am Coll Cardiol* 2018;71:1417–28.
155. Liakopoulos OJ, Gerfer S, Weider S, et al. Direct comparison of the Edwards Intuity Elite and Sorin Perceval S rapid deployment aortic valves. *Ann Thorac Surg* 2018;105:108–14.
156. Harky A, Wong CHM, Hof A, et al. Stented versus stentless aortic valve replacement in patients with small aortic root: a systematic review and meta-analysis. *Innovations (Phila)* 2018;13:404–16.
157. Ennker JAC, Albert AA, Rosendahl UP, Ennker IC, Dalladaku F, Florath I. Ten-year experience with stentless aortic valves: full-root versus subcoronary implantation. *Ann Thorac Surg* 2008;85:445–53.
158. Maxine A, El-Hamamsy I, Verma S, et al. Ross procedure in adults for cardiologists and cardiac surgeons: JACC state-of-the-art review. *J Am Coll Cardiol* 2018;72:2761–77.
159. Weymann A, Sabashnikov A, Popov AF. The Ross procedure: suitable for everyone? *Expert Review Cardiovasc Therapy* 2014;12:549–56.
160. Avierinos JF, Thuny F, Chalvignac V, et al. Surgical treatment of active aortic endocarditis: homografts are not the cornerstone of outcome. *Ann Thorac Surg* 2007;84:1935–42.
161. Gaudino M, De Filippo C, Pennestri F, Possati G. The use of mechanical prostheses in native aortic valve endocarditis. *J Heart Valve Dis* 1997;6:79–83.
162. McCarthy FH, Bavaria JE, Pochettino A, et al. Comparing aortic root replacements: porcine bioroots versus pericardial versus mechanical composite roots: hemodynamic and ventricular remodeling at greater than one-year follow-up. *Ann Thorac Surg* 2012;94:1975–82.
163. Young MN, Singh V, Sakhuja R. A review of alternative access for transcatheter aortic valve replacement. *Curr Treat Options Cardiovasc Med* 2018;20:62.
164. Greenbaum AB, Babaliaros VC, Chen MY, et al. Transcaval access and closure for transcatheter aortic valve replacement: a prospective investigation. *J Am Coll Cardiol* 2017;69:511–21.
165. Mathur M, Krishnan SK, Levin D, Aldea G, Reisman M, McCabe JM. A step-by-step guide to fully percutaneous transaxillary transcatheter aortic valve replacement. *Structural Heart* 2017;1:209–15.
166. Seeger J, Kapadia SR, Kodali S, et al. Rate of peri-procedural stroke observed with cerebral embolic protection during transcatheter aortic valve replacement: a patient-level propensity-matched analysis. *Eur Heart J* 2019;40:1334–40.
167. Kapadia SR, Kodali S, Makkar R, et al. Protection against cerebral embolism during transcatheter aortic valve replacement. *J Am Coll Cardiol* 2017;69:367–77.
168. Bagur R, Solo K, Alghofaili S, et al. Cerebral embolic protection devices during transcatheter aortic valve implantation: systematic review and meta-analysis. *Stroke* 2017;48:1306–15.
169. Murashita T, Schaff HV, Suri RM, et al. Impact of left ventricular systolic function on outcome of correction of severe aortic valve regurgitation: implications for timing of surgical intervention. *Ann Thorac Surg* 2017;103:1222–8.
170. Yoon SH, Schmidt T, Bleizifger S, et al. Transcatheter aortic valve replacement in pure native aortic valve regurgitation. *J Am Coll Cardiol* 2017;70:2752–63.

171. Pettersson GB, Crucean AC, Savage R, et al. Toward predictable repair of regurgitant aortic valves: a systematic morphology-directed approach to bicommissural repair. *J Am Coll Cardiol* 2008;52:40–9.
172. Etz CD, Homann TH, Rane N, et al. Aortic root reconstruction with a bioprosthetic valved conduit: a consecutive series of 275 procedures. *J Thorac Cardiovasc Surg* 2007;133:1455–63.
173. Zannis K, Deux JF, Tzvetkov B, et al. Composite freestyle stentless xenograft with Dacron graft extension for ascending aortic replacement. *Ann Thorac Surg* 2009;87:1789–94.
174. Boodhwani M, de Kerchove L, El Khoury G. Aortic root replacement using the reimplantation technique: tips and tricks. *Interact Cardiovasc Thorac Surg* 2009;8:584–6.
175. Sareyyupoglu B, Suri RM, Schaff HV, et al. Survival and reoperation risk following bicuspid aortic valve sparing root replacement. *J Heart Valve Dis* 2009;18:1–8.
176. David TE, Armstrong S, Maganti M, Colman J, Bradley TJ. Long-term results of aortic valve-sparing operations in patients with Marfan syndrome. *J Thorac Cardiovasc Surg* 2009;138:859–64.
177. Olesen KH. The natural history of 271 patients with mitral stenosis under medical treatment. *Brit Heart J* 1962;24:349–57.
178. Wilkins GT, Weyman AE, Abascal VM, Block PC, Palacios IF. Percutaneous balloon dilatation of the mitral valve: an analysis of echocardiographic variables related to outcome and the mechanism of dilatation. *Br Heart J* 1988;60:299–308.
179. Gentry JL III, Phelan D, Desai MY, Griffin BP. The role of stress echocardiography in valvular heart disease: a current appraisal. *Cardiology* 2017;137:137–150.
180. Passeri JJ, Dal-Bianco JP. Percutaneous mitral valvuloplasty: echocardiographic eligibility and procedural guidance. *Interv Cardiol Clinics* 2018;7:405–13.
181. Song JK, Kim MJ, Yun SC, et al. Long-term outcome of percutaneous mitral balloon valvuloplasty versus open cardiac surgery. *J Thorac Cardiovasc Surg* 2010;139:103–10.
182. Farhat MB, Bussadia H, Ganaddjbakhch I, et al. Closed versus open mitral commissurotomy in pure noncalcific mitral stenosis: hemodynamic studies before and after operation. *J Thorac Cardiovasc Surg* 1990;99:639–44.
183. Choudhury SK, Dhareshwar J, Govli A, Airan B, Kumar AS. Open mitral commissurotomy in the current era: indications, techniques, and results. *Ann Thorac Surg* 2003;75:41–6.
184. Eleid MF. Mitral valve-in-valve/ring and other percutaneous treatments of surgical failures. *Prog Cardiovasc Dis* 2017;60:415–21.
185. Urena M, Himbert D, Brochet E, et al. Transseptal transcatheter mitral valve replacement using balloon-expandable transcatheter heart valves: a step-by-step approach. *JACC Cardiovasc Interv* 2017;10:1905–19.
186. Guerrero M, Eleid M, Foley T, Said S, Rihal C. Transseptal transcatheter mitral valve replacement in severe mitral annular calcification (transseptal valve-in-MAC). *Ann Cardiothorac Surg* 2018;7:830–3.
187. Ad N, Holmes SD, Massimiano PS, Rongione AJ, Fornaresio LM. Long-term outcome following concomitant mitral valve surgery and Cox maze procedure for atrial fibrillation. *J Thorac Cardiovasc Surg* 2018;155:983–94.
188. Badhwar V, Rankin JS, Damiano RJ Jr, et al. The Society of Thoracic Surgeons 2017 Clinical Practice Guidelines for the surgical treatment of atrial fibrillation. *Ann Thorac Surg* 2017;103:329–41.
189. Benedetto U, Melina G, Angeloni E, et al. Prophylactic tricuspid annuloplasty in patients with dilated tricuspid annulus undergoing mitral valve surgery. *J Thorac Cardiovasc Surg* 2012;143:632–8.
190. Chan V, Burwash IG, Lam BK, et al. Clinical and echocardiographic impact of functional tricuspid regurgitation repair at the time of mitral valve replacement. *Ann Thorac Surg* 2009;88:1209–15.
191. Bonow RO, O'Gara PT, Adams DH, Badhwar V, Bavaria JE, Elmariah S, Hung JW, Lindenfeld J, Morris AA, Satpathy R, Whisenant B, YJ Woo. 2020 focused update of the 2017 ACC expert consensus decision pathway on the management of mitral regurgitation. *J Am Coll Cardiol* 2020;75:2236–70.
192. Nishimura RA, Otto CM, Bonow RD, et al. 2017 AHA/ACC focused update of the 2014 AHA/ACC guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* 2017;135:e1159–1193.
193. Coutinho GF, Antunes MJ. Mitral valve repair for degenerative mitral valve disease: surgical approach, patient selection and long-term outcomes. *Heart* 2017;103:1663–9.

194. Zhou T, Li J, Lai H, et al. Benefits of early surgery on clinical outcomes after degenerative mitral valve repair. *Ann Thorac Surg* 2018;106:1063–70.
195. Montant P, Chenot F, Robert A, et al. Long-term survival in asymptomatic patients with severe degenerative mitral regurgitation: a propensity score-based comparison between an early surgical strategy and a conservative treatment approach. *J Thorac Cardiovasc Surg* 2009;138:1339–48.
196. Tomšič A, Hiemstra YL, van Hout FMA, et al. Long-term results of mitral valve repair for severe mitral regurgitation in asymptomatic patients. *J Cardiol* 2018;72:473–9.
197. Nishimura RA, Vahanian A, Eleid MF, Mack MJ. Mitral valve disease: current management and future challenges. *Lancet* 2016;387:1324–34.
198. Feldman T, Kar S, Elmariah S, et al. Randomized comparison of percutaneous repair and surgery for mitral regurgitation: 5-year results of EVEREST II. *J Am Coll Cardiol* 2015;66:2844–54.
199. Pierard LA, Carabello BA. Ischaemic mitral regurgitation: pathophysiology, outcomes, and the conundrum of treatment. *Eur Heart J* 2010;31:2996–3005.
200. Michler RE, Smith PK, Parides MK, et al. Two-year outcomes of surgical treatment of moderate ischemic mitral regurgitation. *N Engl J Med* 2016;374:1932–41.
201. Kopjar T, Gasparovic H, Mestres CA, Milicic D, Biocina B. Meta-analysis of concomitant mitral valve repair and coronary artery bypass surgery versus isolated coronary artery bypass surgery in patients with moderate ischaemic mitral regurgitation. *Eur J Cardiothorac Surg* 2016;50:212–22.
202. Narayanan MA, Aggarwal S, Reddy YNV, et al. Surgical repair of moderate ischemic mitral regurgitation: a systematic review and meta-analysis. *Thorac Cardiovasc Surg* 2017;65:447–56.
203. Virk SA, Tian DH, Sriravindrarajah A, et al. Mitral valve surgery and coronary artery bypass grafting for moderate-severe ischemic mitral regurgitation: meta-analysis of clinical and echocardiographic outcomes. *J Thorac Cardiovasc Surg* 2017;154:127–36.
204. Goldstein D, Moskowitz AJ, Gelijns AC, et al. Two-year outcome of surgical treatment of severe ischemic mitral regurgitation. *N Engl J Med* 2016;374:344–53.
205. Wang X, Zhang B, Zhang J, Ying Y, Zhu C, Chen B. Repair or replacement for severe ischemic mitral regurgitation: a meta-analysis. *Medicine (Baltimore)* 2018;97:e11546.
206. Di Salvo TG, Acker MA, Dec GW, Byrne JG. Mitral valve surgery in advanced heart failure. *J Am Coll Cardiol* 2010;55:271–82.
207. Gorman JH 3rd, Gorman RC. Mitral valve surgery for heart failure: a failed innovation? *Semin Thorac Cardiovasc Surg* 2008;18:135–8.
208. Dayan V, Soca G, Cura L, Mestres CA. Similar survival after mitral valve replacement or repair for ischemic mitral regurgitation: a meta-analysis. *Ann Thorac Surg* 2014;97:758–66.
209. Stone GW, Lindenfeld JA, Abraham WT, et al. Transcatheter mitral-valve repair in patients with heart failure. *N Engl J Med* 2018;379:2307–18.
210. Obadia JF, Messika-Zeitoun D, Leurent G, et al. Percutaneous repair or medical treatment for secondary mitral regurgitation. *N Engl J Med* 2018;279:2297–306.
211. Pibarot P, Delgado V, Bax JJ. MITRA-FR vs. COAPT: lessons from two trials with diametrically opposed results. *Eur Heart J* 2019;20:620–4.
212. Bando K, Kasegawa H, Okada Y, et al. Impact of preoperative and postoperative atrial fibrillation on outcome after mitral valvuloplasty for nonischemic mitral regurgitation. *J Thorac Cardiovasc Surg* 2005;129:1032–40.
213. Gillinov AM, Gelijns AC, Parides MK, et al. Surgical ablation of atrial fibrillation during mitral-valve surgery. *N Engl J Med* 2015;372:1399–409.
214. Marui A, Saji Y, Nishina T, et al. Impact of left atrial reduction concomitant with atrial fibrillation surgery on left atrial geometry and mechanical function. *J Thorac Cardiovasc Surg* 2008; 135:1297–305.
215. Stulak JM, Suri RM, Dearani JA, Sundt TM III, Schaff HV. When should prophylactic Maze procedure be considered in patients undergoing mitral valve surgery? *Ann Thorac Surg* 2010; 89:1395–401.
216. Wan CKN, Suri RM, Li Z, et al. Management of moderate functional mitral regurgitation at the time of aortic valve replacement: is concomitant mitral valve repair necessary? *J Thorac Cardiovasc Surg* 2009;137:635–40.

217. Waisbren EC, Stevens LM, Avery EG, Picard MH, Vlahakes GJ, Agnihotri AK. Changes in mitral regurgitation after replacement of the stenotic aortic valve. *Ann Thorac Surg* 2008;86:56–63.
218. Joo HC, Chang BC, Cho SH, Youn YN, Yoo KJ, Lee S. Fate of functional mitral regurgitation and predictors of persistent mitral regurgitation after isolated aortic valve replacement. *Ann Thorac Surg* 2011;92:82–7.
219. Foster E. Mitral regurgitation due to degenerative mitral-valve disease. *N Engl J Med* 2010;363:156–65.
220. Glower DD. Surgical approaches for mitral regurgitation. *J Am Coll Cardiol* 2012;60:1315–22.
221. Shang E, Forrest GN, Chizmar T, et al. Mitral valve infective endocarditis: benefit of early operation and aggressive use of repair. *Ann Thorac Surg* 2009;87:1728–34.
222. Shimokawa T, Kawegawa H, Matsuyama S, et al. Long-term outcome of mitral valve repair for infective endocarditis. *Ann Thorac Surg* 2009;88:733–9.
223. Tang P, Onatis M, Gaca JG, Milano CA, Stafford-Smith M, Glower D. Right minithoracotomy versus median sternotomy for mitral valve surgery: a propensity matched analysis. *Ann Thorac Surg* 2015;100:575–81.
224. Moscarelli M, Fattouch K, Gaudino M, et al. Minimal access versus sternotomy for complex mitral valve repair: a meta-analysis. *Ann Thorac Surg* 2020;109:737–44.
225. Mihaljevic T, Jarrett CM, Gillinov AM, et al. Robotic repair of posterior mitral valve prolapse versus conventional approaches: potential realized. *J Thorac Cardiovasc Surg* 2011;141:72–80.
226. Murphy DA, Moss E, Binongo J, et al. The expanding role of endoscopic robotics in mitral valve surgery: 1257 consecutive procedures. *Ann Thorac Surg* 2015;100:1675–82.
227. Yang S, Mei B, Feng K, et al. Long-term results of surgical atrial fibrillation radiofrequency ablation: comparison of two methods. *Heart Lung Circ* 2018;27:621–8.
228. Feldman T, Fernandes E, Levisay JP. Transcatheter mitral valve repair/replacement for primary mitral regurgitation. *Ann Cardiothorac Surg* 2018;7:755–63.
229. Savic V, Pozzoli A, Gülmez G, et al. Transcatheter mitral valve chord repair. *Ann Cardiothorac Surg* 2018;7:731–40.
230. Kiefer P, Meier S, Noack T, et al. Good 5-year durability of transapical beating heart off-pump mitral valve repair with neochordae. *Ann Thorac Surg* 2018;106:440–6.
231. Chang JD, Manning WJ, Ebrille E, Zimetbaum PJ. Tricuspid valve dysfunction following pacemaker or cardioverter-defibrillator implantation. *J Am Coll Cardiol* 2017;69:2331–41.
232. Taramasso M, Vanermen, H, Maisano F, Guidotti A, La Canna G, Alfieri O. The growing clinical importance of secondary tricuspid regurgitation. *J Am Coll Cardiol* 2012;59:703–10.
233. Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. *J Am Coll Cardiol* 2004;43:405–9.
234. De Bonis M, Lapenna E, Pozzoli A, et al. Mitral valve repair without repair of moderate tricuspid regurgitation. *Ann Thorac Surg* 2015;100:2206–12.
235. Kara I, Koksal C, Erkin A, et al. Outcomes of mild to moderate functional tricuspid regurgitation in patients undergoing mitral valve operations: a meta-analysis of 2488 patients. *Ann Thorac Surg* 2015;100:2398–407.
236. Navia JL, Brozzi NA, Klein AL, et al. Moderate tricuspid regurgitation with left-sided degenerative heart disease: to repair or not to repair? *Ann Thorac Surg* 2012;93:59–69.
237. Mazine A, Bouchard D, Moss E, et al. Transvalvular pacemaker leads increase the recurrence of regurgitation after tricuspid valve repair. *Ann Thorac Surg* 2013;96:816–22.
238. Benedetto U, Melina G, Angeloni E, et al. Prophylactic tricuspid annuloplasty in patients with dilated tricuspid annulus undergoing mitral valve surgery. *J Thorac Cardiovasc Surg* 2012;143:632–8.
239. Chikwe J, Itagaki S, Anyanwu A, Adams DH. Impact of concomitant tricuspid annuloplasty on tricuspid regurgitation, right ventricular function, and pulmonary artery hypertension after repair of mitral valve prolapse. *J Am Coll Cardiol* 2015;65:1931–8.
240. Dreyfus GD, Corbi PJ, Chan KM, Bahrami T. Secondary tricuspid regurgitation or dilatation: which should be the criteria for surgical repair? *Ann Thorac Surg* 2005;79:127–32.
241. Chan V, Burwash IG, Lam BK, et al. Clinical and echocardiographic impact of functional tricuspid regurgitation repair at the time of mitral valve replacement. *Ann Thorac Surg* 2009;88:1209–15.

242. Kammerlander AA, Marzluf BA, Graf A, et al. Right ventricular dysfunction, but not tricuspid regurgitation, is associated with outcome late after left heart valve procedure. *J Am Coll Cardiol* 2014;64:2633–42.
243. Ghoreishi M, Brown JM, Stauffer CE, et al. Undersized tricuspid annuloplasty rings optimally treat functional tricuspid regurgitation. *Ann Thorac Surg* 2011;92:89–96.
244. Parolari A, Barili F, Pilozzi A, Pacini D. Ring or suture annuloplasty for tricuspid regurgitation: a meta-analysis review. *Ann Thorac Surg* 2014;98:2255–63.
245. Huang X, Gu C, Men X, et al. Repair of functional tricuspid regurgitation: comparison between suture annuloplasty and rings annuloplasty. *Ann Thorac Surg* 2014;97:1286–93.
246. Ren WJ, Zhang BG, Liu JS, Qian YJ, Guo YQ. Outcomes of tricuspid annuloplasty with and without prosthetic rings: a retrospective follow-up study. *J Cardiothorac Surg* 2015;10:81.
247. McCarthy PM, Bhudia SK, Rajeswaran J, et al. Tricuspid valve repair: durability and risk factors for failure. *J Thorac Cardiovasc Surg* 2004;127:674–85.
248. Meng H, Pan SW, Hu SS, Pang KJ, Hou JF, Wang H. Surgical treatment of secondary tricuspid regurgitation: insight derived from annulus sizes and tethering distances. *Ann Thorac Surg* 2015;100:1238–44.
249. Ghanta RK, Chen R, Narayanasamy N, et al. Suture bicuspidization of the tricuspid valve versus ring annuloplasty for repair of functional tricuspid regurgitation: midterm results of 237 consecutive patients. *J Thorac Cardiovasc Surg* 2007;133:117–26.
250. Russo CF, Cannata A, Lanfranconi M, Martinelli L. Destruction of the tricuspid septal leaflet: correction by bicuspidization. *Ann Thorac Surg* 2010;90:1028–9.
251. Isidro AB, Kalra KG, Reis GJ, Pentz WH, Patel VA, Bridges CR. Bicuspidization of the tricuspid valve for the treatment of posterior leaflet endocarditis: a case report. *Heart Surg Forum* 2007;10:e129–30.
252. Garatti A, Nano G, Bruschi G, et al. Twenty-five year outcomes of tricuspid valve replacement comparing mechanical and biologic prostheses. *Ann Thorac Surg* 2012;93:1146–53.
253. Hwang HY, Kim KH, Kim KB, Ahn H. Propensity score matching analysis of mechanical versus bioprosthetic tricuspid valve replacements. *Ann Thorac Surg* 2014;97:1294–9.
254. Filsoufi F, Anyanwu AC, Salzberg SP, Frankel T, Cohn LH, Adams DH. Long-term outcomes of tricuspid valve replacement in the current era. *Ann Thorac Surg* 2005;80:845–50.
255. Civelek A, Ak K, Akgün S, Isbir SC, Arsan S. Tricuspid valve replacement: an analysis of risk factors and outcomes. *Thorac Cardiovasc Surg* 2008;56:456–60.
256. Kilic A, Saha-Chaudhuri P, Rankin JS, Conte JV. Trends and outcomes of tricuspid valve surgery in North America: an analysis of more than 50,000 patients from the Society of Thoracic Surgeons database. *Ann Thorac Surg* 2013;96:1546–52.
257. LaPar DJ, Likosky DS, Zhang M, et al. Development of a risk prediction model and clinical risk score for isolated tricuspid valve surgery. *Ann Thorac Surg* 2018;106:129–37.
258. Nickenig G, Kowalski M, Hausleiter J, et al. Transcatheter treatment of severe tricuspid regurgitation with the edge-to-edge MitraClip technique. *Circulation* 2017;135:1802–14.
259. Perlman G, Praz F, Puri R, et al. Transcatheter tricuspid valve repair with a new transcatheter coaptation system for the treatment of severe tricuspid regurgitation: 1–year clinical and echocardiographic results. *JACC Cardiovasc Interv* 2017;10:1994–2003.
260. Campelo-Parada F, Perlman G, Philippon F, et al. First-in-man experience of a novel transcatheter repair system for treating severe tricuspid regurgitation. *J Am Coll Cardiol* 2015;66:2475–83.
261. Jokinen JJ, Turpeinen AK, Pitkänen O, Hippeläinen MJ, Hartikainen JEK. Pacemaker therapy after tricuspid valve operations: implications on mortality, morbidity, and quality of life. *Ann Thorac Surg* 2009;87:1806–14.
262. Carozza A, De Santo LS, Romano G, et al. Infective endocarditis in intravenous drug abusers: patterns of presentation and long-term outcomes of surgical treatment. *J Heart Valve Dis* 2006;15:125–31.
263. Kim JB, Ejiofor JI, Yammine M, et al. Surgical outcomes of infective endocarditis among intravenous drug users. *J Thorac Cardiovasc Surg* 2016;152:832–41.
264. Cahill TJ, Baddour LM, Habib G, et al. Challenges in infective endocarditis. *J Am Coll Cardiol* 2017;69:3235–44.

265. Alberto San Román J, Vilacosta I, López J, Sarriá C. Critical questions about left-sided infective endocarditis. *J Am Coll Cardiol* 2015;66:1068–76.
266. Tanis W, Scholtens A, Habets J, et al. CT angiography and ^{18}F-FDG-PET fusion imaging for prosthetic heart valve endocarditis. *JACC Cardiovasc Imaging* 2013;6:1008–13.
267. Feuchtner GM, Stolzmann P, Diehtl W, et al. Multislice computed tomography in infective endocarditis: comparison with transesophageal echocardiography and operative findings. *J Am Coll Cardiol* 2009;53:436–44.
268. Yashioka D, Toda K, Okazaki S, et al. Anemia is a risk factor for new intraoperative hemorrhagic stroke during valve surgery for endocarditis. *Ann Thorac Surg* 2015;100:16–23.
269. Habib G, Lancellotti P, Antunes MJ, et al. 2015 ESC guidelines for the management of infective endocarditis: the Task Force for the management of infective endocarditis of the European Society of Cardiology (ESC). *Eur Heart J* 2015;36:3075–128.
270. Vilacosta I, Graupner C, San Román A, et al. Risk of embolization after institution of antibiotic therapy for infective endocarditis. *J Am Coll Cardiol* 2002;39:1489–95.
271. Dickerman SA, Abrutyn E, Barsic B, et al. The relationship between the initiation of antimicrobial therapy and the incidence of stroke in infective endocarditis: analysis from the ICE prospective cohort study (ICS-PCS). *Am Heart J* 2007;154:1086–94.
272. Hubert S, Thuny F, Resseguier M, et al. Prediction of symptomatic embolism in infective endocarditis: construction and validation of a risk calculator in a multicenter cohort. *J Am Coll Cardiol* 2013;62:1384–92.
273. Kang DH, Kim YJ, Kim SH, et al. Early surgery versus conventional treatment for infective endocarditis. *N Engl J Med* 2012;366:2466–73.
274. Yoshioka D, Sakaguchi T, Yamauchi T, et al. Impact of early surgical treatment on postoperative neurologic outcome for active infective endocarditis complicated by cerebral infarction. *Ann Thorac Surg* 2012;94:489–96.
275. Hussain ST, Witten J, Shreshtha NK, Blackstone EH, Pettersson GB. Tricuspid valve endocarditis. *Ann Cardiothorac Surg* 2017;6:255–61.
276. Yanagawa B, Elbatarny M, Verma S, et al. Surgical management of tricuspid valve infective endocarditis: a systematic review and meta-analysis. *Ann Thorac Surg* 2018;106:708–15.
277. Prendergast BD, Tornos P. Surgery for infective endocarditis: who and when? *Circulation* 2010;121:1141–52.
278. Witten JC, Hussain ST, Shrestha NK, et al. Surgical treatment of right-sided infective endocarditis. *J Thorac Cardiovasc Surg* 2019;157:1418–27.
279. Shrestha NK, Jue J, Hussain ST, et al. Injection drug use and outcomes after surgical intervention for infective endocarditis. *Ann Thorac Surg* 2015;100:875–83.
280. Rabkin DG, Mokadam NA, Miller DW, Goetz RR, Verrier ED, Aldea GS. Long-term outcome for the surgical treatment of infective endocarditis with a focus on intravenous drug users. *Ann Thorac Surg* 2012;93:51–8.
281. Dawood MY, Cheema FH, Ghoreishi M, et al. Contemporary outcomes of operations for tricuspid valve infective endocarditis. *Ann Thorac Surg* 2015;99:539–46.
282. Braun MU, Rauwolf T, Bock M, et al. Percutaneous lead implantation connected to an external device in stimulation dependent patients with systemic infection: a prospective and controlled study. *Pacing Clin Electrophysiol* 2006;29:875–9.
283. Shroff GR, Herzog CA, Ma JZ, Collins AJ. Long-term survival of dialysis patients with bacterial endocarditis in the United States. *Am J Kidney Dis* 2004;44:1077–82.
284. Nori US, Manoharan A, Thornby JI, Yee J, Parasuraman R, Ramanathan V. Mortality risk factors in chronic haemodialysis patients with infective endocarditis. *Neph Dialysis Transplant* 2006;21:2184–90.
285. Dohmen PM, Binner C, Mende M, et al. Outcome of aortic valve replacement for active infective endocarditis in patients on chronic hemodialysis. *Ann Thorac Surg* 2015;99:532–8.
286. Farrington DK, Kilgo PD, Thourani VH, Jacob JT, Steinberg JP. High risk of prosthetic valve endocarditis and death after valve replacement operations in dialysis patients. *Ann Thorac Surg* 2016;101:2217–23.
287. Herzog CA, Ma JZ, Collins AJ. Long-term survival of dialysis patients in the United States with prosthetic heart valves: should ACC/AHA practice guidelines on valve selection be modified? *Circulation* 2002;105:1336–41.

288. Ando T, Ashraf S, Villablanca PA, et al. Meta-analysis comparing the incidence of infective endocarditis following transcatheter aortic valve implantation versus surgical aortic valve replacement. *Am J Cardiol* 2019;123:827–32.
289. Butt JW, Ihlemann N, De Backer O, et al. Long-term risk of infective endocarditis after transcatheter aortic valve replacement. *J Am Coll Cardiol* 2019;73:1646–55.
290. Byrne JG, Rezai K, Sanchez JA, et al. Surgical management of endocarditis: the Society of Thoracic Surgeons Clinical Practice Guidelines. *Ann Thorac Surg* 2011;91:2012–9.
291. Sultan I, Bianco V, Kilic A, Chu D, Navid F, Gleason TG. Aortic root replacement with cryopreserved homograft for infective endocarditis in the modern North American opioid epidemic. *J Thorac Cardiovasc Surg* 2019;157:45–50.
292. Jassar AS, Bavaria JE, Szeto WY, et al. Graft selection for aortic root replacement in complex active endocarditis: does it matter? *Ann Thorac Surg* 2012;93:480–8.
293. Toyoda N, Itagaki S, Tannous H, Egorova NN, Chikwe J. Bioprosthetic versus mechanical valve replacement for infective endocarditis: focus on recurrence rates. *Ann Thorac Surg* 2018;106:99–106.
294. Rostagno C, Carone E, Stefano PL. Role of mitral valve repair in active infective endocarditis: long-term results. *J Cardiothorac Surg* 2017;12:29.
295. Protos AN, Trivedi JR, Whited WM, et al. Valvectomy versus replacement for the surgical treatment of tricuspid endocarditis. *Ann Thorac Surg* 2018;106:664–9.
296. Sherrid MV, Balaram S, Kim B, Axel L, Swistel DG. The mitral valve in obstructive hypertrophic cardiomyopathy: a test in context. *J Am Coll Cardiol* 2016;67:1846–58.
297. Maron BJ, Ommen SR, Semsarian C, Spirito P, Olivotto I, Maron MS. Hypertrophic cardiomyopathy: present and future, with translation into contemporary cardiovascular medicine. *J Am Coll Cardiol* 2014;64:83–99.
298. Maron BJ, Rowin EJ, Udelson JE, Maron MS. Clinical spectrum and management of heart failure in hypertrophic cardiomyopathy. *JACC Heart Failure* 2018;6:653–63.
299. Geske JB, Ommen SR, Gersh BJ. Hypertrophic cardiomyopathy: clinical update. *JACC Heart Failure* 2018;6:364–75.
300. Maron BJ. Clinical course and management of hypertrophic cardiomyopathy. *N Engl J Med* 2018;379:655–68.
301. Maron MS, Rowin EJ, Olivotto I, et al. Contemporary natural history and management of nonobstructive hypertrophic cardiomyopathy. *J Am Coll Cardiol* 2016;67:1399–409.
302. Chan RH, Maron BJ, Olivotto I, et al. Prognostic value of quantitative contrast-enhanced cardiovascular magnetic resonance for the evaluation of sudden death risk in patients with hypertrophic cardiomyopathy. *Circulation* 2014;130:484–95.
303. Weng Z, Yao J, Chan RH, et al. Prognostic value of LGE-CMR in HCM: a meta-analysis. *JACC Cardiovasc Imaging* 2016;9:1392–1402.
304. Price J, Clarke N, Turer A, et al. Hypertrophic obstructive cardiomyopathy: review of surgical treatment. *Asian Cardiovasc Thorac Ann* 2017;25:594–607.
305. Parry DJ, Raskin RE, Poynter JA, et al. Short and medium term outcomes of surgery for patients with hypertrophic obstructive cardiomyopathy. *Ann Thorac Surg* 2015;99:1213–9.
306. Hong JH, Schaff HV, Nishimura RA, et al. Mitral regurgitation in patients with hypertrophic obstructive cardiomyopathy: implications for concomitant valve procedures. *J Am Coll Cardiol* 2016;68:1497–504.
307. Liebreghts M, Vriesendorp PA, Majmoodi BK, Schinkel AE, Michels M, ten Berg JM. A systematic review and meta-analysis of long-term outcomes after septal reduction therapy in patients with hypertrophic cardiomyopathy. *JACC Heart Fail* 2015;3:896–905.
308. Gupta S, Slater M, Heitner S, Wei K. TCT-810 percutaneous mitral valve repair for management of systolic anterior motion and mitral regurgitation associated with hypertrophic cardiomyopathy. *J Am Coll Cardiol* 2016;68: doi: 10.1016/j.jacc.2016.09.842.
309. Evangelista A, Isselbacher EM, Bossone, E, et al. Insights from the International Registry of Acute Aortic Dissection: a 20-year experience of collaborative clinical research. *Circulation* 2018;137:1846–60.
310. Goldfinger JZ, Halperin JL, Marin ML, Stewart AS, Eagle KA, Fuster V. Thoracic aortic aneurysm and dissection. *J Am Coll Cardiol* 2014;64:1725–39.

311. Elefteriades JA, Farkas EA. Thoracic aortic aneurysm: clinical pertinent controversies and uncertainties. *J Am Coll Cardiol* 2010;55:841–57.
312. Hansen MS, Nogareda GJ, Hutchison FJ. Frequency of and inappropriate treatment of misdiagnosis of acute aortic dissection. *Am J Cardiol* 2007;99:852–6.
313. Bonser RS, Ranasinghe AM, Loubani M, et al. Evidence, lack of evidence, controversy, and debate in the provision and performance of the surgery of acute type A aortic dissection. *J Am Coll Cardiol* 2011;58:2455–74.
314. Pape LA, Awais M, Woznicki EM, et al. Presentation, diagnosis, and outcomes of acute aortic dissection: 17-year trends from the International Registry of Acute Aortic Dissection. *J Am Coll Cardiol* 2015;66:350–8.
315. Rogers AM, Hermann LK, Booher AM, et al. Sensitivity of the aortic dissection detection risk score, a novel guideline-based tool for identification of acute aortic dissection at initial presentation: results from the International Registry of Acute Aortic Dissection. *Circulation* 2011;123:2213–8.
316. Czerny M, Schoenhoff F, Etz C, et al. The impact of pre-operative malperfusion on outcome in acute type A aortic dissection: results from the GERAADA Registry. *J Am Coll Cardiol* 2015;65:2628–35.
317. Suzuki T, Distante A, Zizza A, et al. Diagnosis of acute aortic dissection by D-Dimer: the International Registry of Acute Aortic Dissection substudy on biomarkers (IRAD-Bio) experience. *Circulation* 2009;119:2702–7.
318. Paparella D, Malvindi PG, Scrascia G, et al. D-dimers are not always elevated in patients with acute dissection. *J Cardiovasc Med (Hagerstown)* 2009;10:212–4.
319. Nazerian P, Mueller C, Soeiro AM, et al. Diagnostic accuracy of the Aortic Dissection Detection Risk Score plus D-Dimer for acute aortic syndromes: The ADvISED Prospective Multicenter Study. *Circulation* 2018;137:1846–60.
320. Patel HJ, Williams DM, Dasika NL, Suzuki Y, Deeb GM. Operative delay for peripheral malperfusion syndrome in acute type A aortic dissection: a long-term analysis. *J Thorac Cardiovasc Surg* 2008;135:1288–96.
321. Yagdi T, Atay Y, Engin C, et al. Impact of organ malperfusion on mortality and morbidity in acute type A aortic dissections. *J Card Surg* 2006;21:363–9.
322. Fattori R, Cao P, De Rango P, et al. Interdisciplinary expert consensus document on management of type B aortic dissection. *J Am Coll Cardiol* 2013;61:1661–78.
323. Nauta AJH, Trimarchi S, Kamman AV, et al. Update in the management of type B aortic dissection. *Vasc Med* 2016;21:251–63.
324. Moulakakis KG, Mylonas SN, Daleinas I, Kakisis J, Kotsis T, Liapis CD. Management of complicated and uncomplicated acute type B dissection: a systematic review and meta-analysis. *Ann Cardiothorac Surg* 2014;3:234–46.
325. Tadros ROI, Tang GHL, Barnes JH, et al. Optimal treatment of uncomplicated type B aortic dissection. *J Am Coll Cardiol* 2019;74:1494–504.
326. Cruz I, Stuart B, Caldeira D, et al. Controlled pericardiocentesis in patients with cardiac tamponade complicating aortic dissection: experience of a centre without cardiothoracic surgery. *Eur Heart J Acute Cardiovasc Care* 2015;4:112–22.
327. Hayashi T, Tsukube T, Yamashita T, et al. Impact of controlled pericardial drainage on critical cardiac tamponade with acute type A aortic dissection. *Circulation* 2012;126(11 Suppl 1):S97–S101.
328. Tagagi H, Uemoto T, ALICE Group. A meta-analysis of total arch replacement with frozen elephant trunk in acute type A aortic dissection. *Vasc Endovascular Surg* 2016;50:33–46.
329. Poon SS, Theologou T, Harrington D, Kuduvalli M, Oo A, Field M. Hemiarch versus total aortic arch replacement in acute type A dissection: a systematic review and meta-analysis. *Ann Cardiothorac Surg* 2016;5:15–73.
330. Masalanis G, Ip S. A new paradigm in the management of acute type A aortic dissection: total aortic repair. *J Thorac Cardiovasc Surg* 2019;157:3–11.
331. Geirsson A, Szeto WY, Pochettino A, et al. Significance of malperfusion syndromes prior to contemporary surgical repair for acute type A dissection: outcomes and need for additional revascularization. *Eur J Cardiothorac Surg* 2007;32:255–62.
332. Geirsson A, Shioda K, Olsson C, et al. Differential outcomes of open and clamp-on distal anastomotic techniques in acute type A aortic dissection. *J Thorac Cardiovasc Surg* 2019;157:1750–8.

333. Abe T, Usui A. The cannulation strategy in surgery for acute type A dissection. *Gen Thorac Cardiovasc Surg* 2017;65:1–9.
334. Stamou SC, Gartner D, Kouchoukos NT, et al. Axillary versus femoral arterial cannulation during repair of type A aortic dissection? An old problem seeking new solutions. *Aorta (Stamford)* 2016;4:115–123.
335. Trimarchi S, de Beauafort HWL, Tolenaar JL, et al. Acute aortic dissections with entry tear in the arch: a report from the International Registry of Acute Aortic Dissection. *J Thorac Cardiovasc Surg* 2019;157:66–73.
336. Sun L, Qi R, Chang Q, et al. Surgery for acute type A dissection with the tear in the descending aorta using a stented elephant trunk procedure. *Ann Thorac Surg* 2009;87:1177–81.
337. Chen Y, Zhang S, Liu L, Qingsheng L, Zhang T, Jing Z. Retrograde type A aortic dissection after thoracic endovascular aortic repair: a systematic review and meta-analysis. *J Am Heart Assoc* 2017;6:e004649.
338. Zafar MA, Li Y, Rizzo JA, et al. Height alone, rather than body surface area, suffices for risk stratification in ascending aortic aneurysm. *J Thorac Cardiovasc Surg* 2018;155:1938–50.
339. Kim JB, Spotnitz M, Lindsay ME, MacGillvray TE, Isselbacher EM, Sundt TM, III. Risk of aortic dissection in the moderately dilated ascending aorta. *J Am Coll Cardiol* 2016;68:1209–19.
340. Nishimura RA, Ott CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force Practice Guideline. *J Am Coll Cardiol* 2014;63:e57–185.
341. Hiratzka LF, Bakris FL, Beckmann JA, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with thoracic aortic disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association of Thoracic Surgery, American College of Radiology, American Stroke Association, American Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *Circulation* 2010;121:1544–79.
342. Hiratzka LF, Creager MA, Isselbacher EM, Svensson LG. Surgery for aortic dilatation in patients with bicuspid aortic valves. A statement of clarification from the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol* 2016;67:724–31.
343. Masri A, Kalahasti V, Svensson G, et al. Aortic cross-sectional area/height ratio and outcomes in patients with a trileaflet aortic valve and a dilated aorta. *Circulation* 2016;134:1724–37.
344. Ziganshin BA, Zafar MA, Elefteriades JA. Descending threshold for ascending aortic aneurysmectomy: is it time for a "left-shift" in guidelines? *J Thorac Cardiovasc Surg* 2019;157:37–42.
345. Prenger K, Pieters F, Cheriex E. Aortic dissection after valve replacement: incidence and consequences for strategy. *J Card Surg* 1994;9:495–8.
346. Pape LA, Tsai TT, Isselbacher EM, et al. Aortic diameter > or = 5.5 cm is not a good predictor of type A aortic dissection: observations from the International Registry of Acute Aortic Dissection (IRAD). *Circulation* 2007;116:1120–7.
347. Davies RR, Gallo A, Coady MA, et al. Novel measurement of relative aortic size predicts rupture of thoracic aortic aneurysms. *Ann Thorac Surg* 2006;81:169–77.
348. Matura LA, Ho VB, Rosing DR, Bondy CA. Aortic dilatation and dissection in Turner syndrome. *Circulation* 2007;116:1663–70.
349. Svensson LF, Adams DH, Bonow RO, et al. Aortic valve and ascending aorta guidelines for management and quality measures: executive summary. *Ann Thorac Surg* 2013;95:1491–505.
350. Svensson LG, Khitin L. Aortic cross-sectional area/height ratio timing of aortic surgery in asymptomatic patients with Marfan syndrome. *J Thorac Cardiovasc Surg* 2002;123:360–1.
351. Svensson LG, Kim KH, Lytle BW, Cosgrove DM. Relationship of aortic cross-sectional area to height ratio and the risk of aortic dissection in patients with bicuspid aortic valves. *J Thorac Cardiovasc Surg* 2003;126:892–3.
352. Wu J, Zafar MA, Li Y, et al. Ascending aortic length and risk of aortic adverse events: the neglected dimension. *J Am Coll Cardiol* 2019;74:1883–94.

353. Fazel SS, Mallidi HR, Lee RS, et al. The aortopathy of bicuspid aortic valve disease has distinctive patterns and usually involves the transverse aortic arch. *J Thorac Cardiovasc Surg* 2008;135:901–7.
354. Mookhoek A, Korteland NM, Arabkhani B, et al. Bentall procedure: a systematic review and meta-analysis. *Ann Thorac Surg* 2016;101:1684–9.
355. Bianco V, Kilic A, Gleason TG, et al. Aortic root replacement with stentless xenografts in patients with aortic stenosis. *J Thorac Cardiovasc Surg* 2019;158:1021–7.
356. Price J, Magruder JT, Young A, et al. Long-term outcomes of aortic root operations for Marfan syndrome: a comparison of Bentall versus aortic valve-sparing procedures. *J Thorac Cardiovasc Surg* 2016;151:330–6.
357. Ouzounian M, Feindel CM, Manlhiot C, David C, David TE. Valve-sparing root replacement with bicuspid versus tricuspid aortic valves. *J Thorac Cardiovasc Surg* 2019;158:1–9.
358. Tian DH, Weller J, Hasmat S, et al. Adjunct retrograde cerebral perfusion provides superior outcomes compared with hypothermic circulatory arrest alone: a meta-analysis. *J Thorac Cardiovasc Surg* 2018;156:1339–48.
359. Fan S, Li H, Wang D, et al. Effects of four major brain protection strategies during proximal aortic surgery: a systematic review and network meta-analysis. *Int J Surg* 2019;63:8–15.
360. Perreas K, Samanitis G, Thanopoulos A, et al. Antegrade or retrograde cerebral perfusion in ascending aorta and hemiarch surgery? A propensity-matched analysis. *Ann Thorac Surg* 2018;101:146–52.
361. Numata S, Tsutsumi Y, Monta O, et al. Aortic arch repair with antegrade selective cerebral perfusion using mild to moderate hypothermia of more than 28 °C. *Ann Thorac Surg* 2012;94:90–6.
362. Itagaki S, Chikwe J, Sun E, Chu E, Toyoda N, Egorova N. Impact of cerebral perfusion on outcomes of aortic surgery: the Society of Thoracic Surgeons adult cardiac surgery database analysis. *Ann Thorac Surg* 2020;109:428–36.
363. Lau C, Gaudino M, Iannaconne EM, et al. Retrograde cerebral perfusion is effective for prolonged circulatory arrest in arch aneurysm repair. *Ann Thorac Surg* 2018;105:491–7.
364. Pérez MA, Coto JML, del Castro Madrazo JA, Prendes CF, Gay MG, Al-Sibbai AZ. Debranching aortic surgery. *J Thorac Dis* 2017;9(suppl 6):S465–S477.
365. Spielvogel D, Etz CD, Silovitz D, Lansman SL, Griepp RB. Aortic arch replacement with a trifurcated graft. *Ann Thorac Surg* 2007;83:S791–5.
366. Etz CD, Plestis KA, Kari FA, et al. Staged repair of thoracic and thoracoabdominal aortic aneurysms using the elephant trunk technique: a consecutive series of 215 first stage and 120 complete repairs. *Eur J Cardiothorac Surg* 2008;34:605–14.
367. Koizumi S, Nagasawa A, Koyama T. Total aortic arch replacement using frozen elephant trunk technique with J Graft Open Stent Graft for distal aortic arch aneurysm. *Gen Thorac Cardiovasc Surg* 2018;66:91–4.
368. Estrera AL, Miller CC III, Chen EP, et al. Descending thoracic aortic aneurysm repair: a 12-year experience using distal aortic perfusion and cerebrospinal fluid drainage. *Ann Thorac Surg* 2005;80:1290–6.
369. Estrera AL, Sheinbaum R, Miller CC, et al. Cerebrospinal fluid drainage during thoracic aortic repair: safety and current management. *Ann Thorac Surg* 2009;88:9–15.
370. Tanaka A, Safi HJ, Estrera AL. Current strategies of spinal cord protection during thoracoabdominal aortic surgery. *Gen Thorac Cardiovasc Surg* 2018;66:307–14.
371. Coselli JS, LeMaire SA, Conklin LD, Adams GJ. Left heart bypass during descending thoracic aortic aneurysm repair does not reduce the incidence of paraplegia. *Ann Thorac Surg* 2004;77:1298–303.
372. Cheng D, Martin J, Shennib H, et al. Endovascular aortic repair versus open surgical repair for descending thoracic aortic disease: a systematic review and meta-analysis of comparative studies. *J Am Coll Cardiol* 2010;55:986–1001.
373. Chiu P, Goldstone AB, Schaffer JM, et al. Endovascular versus open repair of intact descending thoracic aneurysms. *J Am Coll Cardiol* 2019;73:643–51.
374. Hnath JC, Mehta M, Taggert JB, et al. Strategies to improve spinal cord ischemia in endovascular thoracic aortic repair: outcomes of a prospective cerebrospinal fluid drainage protocol. *J Vasc Surg* 2008;48:836–40.

375. Calkins H, Hindricks G, Cappato R, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation. *Heart Rhythm* 2017;14:e275–444. and *Europace* 2018;20:e1–160.
376. Ad N, Damiano RJ Jr, Badhwar V, et al. Expert consensus guidelines: examining surgical ablation for atrial fibrillation. *J Thorac Cardiovasc Surg* 2017;153:1330–54.
377. Khawar W, Smith N, Masroor S. Managing the left atrial appendage in atrial fibrillation: current state of the art. *Ann Thorac Surg* 2017;104:2111–9.
378. Turagam K, Velagapudi P, Kar S, et al. Cardiovascular therapies targeting left atrial appendage. *J Am Coll Cardiol* 2018;72:448–63.
379. Barnett SD, Ad N. Surgical ablation as treatment for the elimination of atrial fibrillation: a meta-analysis. *J Thorac Cardiovasc Surg* 2006;131:1029–35.
380. Gillinov M, Soltsz E. Surgical treatment of atrial fibrillation: today's questions and answers. *Semin Thorac Cardiovasc Surg* 2013;25:197–205.
381. Philpott JM, Zemlin CW, Cox JL, et al. The ABLATE trial: safety and efficacy of Cox Maze-IV using a bipolar radiofrequency ablation system. *Ann Thorac Surg* 2015;100:1541–8.
382. Churyla A, Iddriss A, Andrei AC, et al. Biatrial or left atrial lesion set for ablation during mitral surgery: risks and benefits. *Ann Thorac Surg* 2017;103:1858–65.
383. Kim JB, Bang JH, Jung SH, Choo SJ, Chung CH, Lee JW. Left atrial ablation versus biatrial ablation in the surgical treatment of atrial fibrillation. *Ann Thorac Surg* 2011;92:1397–405.
384. Cappabianca G, Ferrarese S, Tutino C, et al. Safety and efficacy of biatrial vs left atrial surgical ablation during concomitant cardiac surgery: a meta-analysis of clinical studies with a focus on the causes of pacemaker implantation. *J Cardiovasc Electrophys* 2019;30:2150–63.
385. Geidel S, Krause K, Boczor S, Kuck KH, Lass M, Ostermeyer J, Schmoeckel M. Ablation surgery in patients with persistent atrial fibrillation: an 8-year clinical experience. *J Thorac Cardiovasc Surg* 2011;141:377–82.
386. Ad N, Holmes SD, Shuman DJ, Pritchard G. Impact of atrial fibrillation duration on the success of first-time concomitant Cox maze procedures. *Ann Thorac Surg* 2015;100:1613–9.
387. Ad N, Holmes SD. Prediction of sinus rhythm in patients undergoing concomitant Cox maze procedure through a median sternotomy. *J Thorac Cardiovasc Surg* 2014;148:881–7.
388. Stulak JM, Dearani JA, Sundt TM III, Daly RC, Schaff HV. Ablation of atrial fibrillation: comparison of catheter-based techniques and the Cox-Maze III operation. *Ann Thorac Surg* 2011;91:1882–9.
389. Damiano RJ Jr, Badhwar V, Acker MA, et al. The CURE-AF trial: a prospective, multicenter trial of irrigated radiofrequency ablation for the treatment of persistent atrial fibrillation during concomitant cardiac surgery. *Heart Rhythm* 2014;11:39–45.
390. Ad N, Holmes SD, Massimiano PS, Rongione AJ, Fornaresio LM. Long-term outcome following concomitant mitral valve surgery and Cox maze procedure for atrial fibrillation. *J Thorac Cardiovasc Surg* 2018;155:983–94.
391. Gillinov AM, Gelijns AC, Parides MK, et al. Surgical ablation of atrial fibrillation during mitral-valve surgery. *N Engl J Med* 2015;372:1399–409.
392. Henn MC, Lawrance CP, Sinn LA, et al. Effectiveness of surgical ablation in patients with atrial fibrillation and aortic valve disease. *Ann Thorac Surg* 2015;100:1253–9.
393. Al-Atassi T, Kimmaliardjuk DM, Dagenais C, Bourke M, Lam BK, Rubens FD. Should we ablate atrial fibrillation during coronary artery bypass grafting and aortic valve replacement? *Ann Thorac Surg* 2017;104:515–22.
394. Marui A, Saji Y, Nishina T, et al. Impact of left atrial reduction concomitant with atrial fibrillation surgery on left atrial geometry and mechanical function. *J Thorac Cardiovasc Surg* 2008;135:1297–305.
395. Doll N, Pritzwald-Stegmann P, Czesla M, et al. Ablation of ganglionic plexi during combined surgery for atrial fibrillation. *Ann Thorac Surg* 2008;86:1659–63.
396. Tsai YC, Phan K, Munkholm-Larsen S, Tian DH, La Meir M, Yan TD. Surgical left atrial appendage occlusion during cardiac surgery for patients with atrial fibrillation: a meta-analysis. *Eur J Cardiothorac Surg* 2015;47:847–54.
397. Buber J, Luria D, Sternik L, et al. Left atrial contractile function following a successful modified Maze procedure at surgery and the risk for subsequent thromboembolic stroke. *J Am Coll Cardiol* 2011;58:1614–21.

398. Edgerton JR, Jackman WM, Mack MJ. A new epicardial lesion set for minimal access left atrial Maze: the Dallas lesion set. *Ann Thorac Surg* 2009;88:1655–7.
399. Edgerton JR, Brinkman WT, Weaver T, et al. Pulmonary vein isolation and autonomic denervation for the management of paroxysmal atrial fibrillation by a minimally invasive surgical approach. *J Thorac Cardiovasc Surg* 2010;140:823–8.
400. Gersak B, Jan M. Long-term success from the convergent atrial fibrillation procedure: 4-year outcome. *Ann Thorac Surg* 2016;102:1550–7.
401. Yancy CW, Jessup M, Bozkurt, et al. 2013 ACCF/AHA guidelines for the management of heart failure. *J Am Coll Cardiol* 2013;62:e147–239.
402. Yancy CW, Jessup M, Bozkurt B, et al. 2017 ACC/AHA/HFSA focused update of the 2013 ACCF/AHA guidelines for the management of heart failure. *J Am Coll Cardiol* 2017;70:776–803.
403. Mancini D, Colombo PC. Left ventricular assist devices: a rapidly evolving alternative to transplant. *J Am Coll Cardiol* 2015;65:2542–55.
404. Shah KB, Starling RC, Rogers JG, et al. Left ventricular assist devices versus medical management in ambulatory heart failure patients: an analysis of INTERMACS Profiles 4 and 5 to 7 from the ROADMAP study. *J Heart Lung Transplant* 2018;37:706–14.
405. Diodato MD, Moon MR, Pasque MK. Repair of ischemic mitral regurgitation does not increase mortality or improve long-term survival in patients undergoing coronary artery revascularization: a propensity analysis. *Ann Thorac Surg* 2004;78:794–9.
406. Fattouch K, Guccione F, Sampognaro R, et al. POINT: efficacy of adding mitral valve restrictive annuloplasty to coronary artery bypass grafting in patients with moderate ischemic mitral valve regurgitation: a randomized trial. *J Thorac Cardiovasc Surg* 2009;138:278–85.
407. Onarati G, Rubino AS, Marturano D, et al. Mid-term clinical and echocardiographic results and predictors of mitral regurgitation recurrence following restrictive annuloplasty for ischemic cardiomyopathy. *J Thorac Cardiovasc Surg* 2009;138:654–62.
408. Braun J, van de Veire NR, Klautz RJ, et al. Restrictive mitral annuloplasty cures ischemic mitral regurgitation and heart failure. *Ann Thorac Surg* 2008;85:430–6.
409. Samad Z, Shaw LK, Phelan M. Management and outcomes in patients with moderate or severe functional mitral regurgitation and severe left ventricular dysfunction. *Eur Heart J* 2015;36:2733–41.
410. ten Brinke EA, Klautz RJ, Tulner SA, et al. Clinical and functional effects of restrictive mitral annuloplasty at midterm follow-up in heart failure patients. *Ann Thorac Surg* 2010;90:1913–21.
411. Kutyifa V, Quesada B, Klein H, et al. Long-term outcomes of cardiac resynchronization therapy in asymptomatic heart failure patients. *J Am Coll Cardiol* 2018;71 (suppl):10–2.
412. Al-Ghamdi B. Subcutaneous implantable cardioverter defibrillators: an overview of implantation techniques and clinical outcomes. *Current Cardiology Reviews* 2019;15:38–48.
413. Al-Khalib SM, Stephenson WG, Ackerman MJ, et al. 2017 AHA/ACC/HRS guideline for management of patients with ventricular arrhythmias and the prevention of sudden death: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Heart Rhythm Society. *Circulation* 2018;138:e272–391.
414. Castelvecchio S, Garatti A, Gagliardotto PV, Menicanti L. Surgical ventricular reconstruction for ischaemic heart failure: state of the art. *Eur Heart J* 2016;18:e8–14.
415. Buckberg G, Athanasuleas C, Conte J. Surgical ventricular restoration for the treatment of heart failure. *Nat Rev Cardiol* 2012;9:703–16.
416. Ribeiro GA, da Costa CE, Lopes M, et al. Left ventricular reconstruction benefits patients with ischemic cardiomyopathy and non-viable myocardium. *Eur J Cardiothorac Surg* 2006;29:196–201.
417. Jones RH, Velazquez EJ, Michler RE, et al. Coronary bypass surgery with or without ventricular reconstruction. *N Engl J Med* 2009;360:1705–17.
418. Michler RE, Rouleau J, Al-Khalidi HR, et al. Insights from the STICH trial: change in left ventricular size after coronary artery bypass grafting with and without surgical ventricular restoration. *J Thorac Cardiovasc Surg* 2013;146:1139–45.
419. Witkowski TG, ten Brinke EA, Delgado V, et al. Surgical ventricular restoration for patients with ischemic heart failure: determinants of two-year survival. *Ann Thorac Surg* 2011;91:491–8.

420. Prucz RB, Weiss ES, Patel ND, Nwakanma LU, Shah AS, Conte JV. The impact of surgical ventricular restoration on mitral valve regurgitation. *Ann Thorac Surg* 2008;86:726–34.
421. Fukunaga N, Rao V. Left ventricular assist device as destination therapy for end stage heart failure: the right time for the right patients. *Curr Opin Cardiol* 2018;33:196–201.
422. Pérez-Casares, Cesar S, Brunet-Garcia L, Sanchez-de-Toledo J. Echocardiographic evaluation of pericardial effusion and cardiac tamponade. *Front Pediatr* 2017;5:79.
423. Depboylu BC, Mootoosamy P, Vistarini N, Testuz A, El-Hamamsy I, Cikirikcioglu M. Surgical treatment of constrictive pericarditis. *Tex Heart Int J* 2017;44:101–6.
424. Miranda WR, Oh JK. Constrictive pericarditis: a practical clinical approach. *Prog Cardiovasc Dis* 2017;59:369–79.
425. Geske JB, Anavekar NS, Nishimura RA, Oh JK, Gersh B. Differentiation of constriction and restriction: complex cardiovascular hemodynamics. *J Am Coll Cardiol* 2016;68:2329–47.
426. Rajagopalan N, Garcia MJ, Rodriguez L, et al. Comparison of new Doppler echocardiographic methods to differentiate constrictive pericardial disease and restrictive cardiomyopathy. *Am J Cardiol* 2001;87:86–94.
427. Ziskind AA, Pearce AC, Lemmon CC, et al. Percutaneous balloon pericardiotomy for the treatment of cardiac tamponade and large pericardial effusions: description of technique and report of the first 50 cases. *J Am Coll Cardiol* 1993;21:1–5.
428. Ha HW, Oh JK, Schaff HV, et al. Impact of left ventricular function on immediate and long-term outcomes after pericardiectomy in constrictive pericarditis. *J Thorac Cardiovasc Surg* 2008;136:1136–41.
429. Allen KB, Faber LP, Warren WH, Shaar CJ. Pericardial effusion: subxiphoid pericardiostomy versus percutaneous catheter drainage. *Ann Thorac Surg* 1999;67:437–40.
430. O'Brien PK, Kucharczuk JC, Marshall MB, et al. Comparative study of subxiphoid versus video-thoracoscopic pericardial "window". *Ann Thorac Surg* 2005;80:2013–9.
431. Bertog SC, Thambidorai SK, Parakh K, et al. Constrictive pericarditis: etiology and cause-specific survival after pericardiectomy. *J Am Coll Cardiol* 2004;43:1445–52.
432. Meissner I, Khandheria BK, Heit JA, et al. Patent foramen ovale: innocent or guilty? Evidence from a prospective population-based study. *J Am Coll Cardiol* 2006;47:440–5.
433. Lamy C, Giannesini C, Zuber M, et al. Clinical and imaging findings in cryptogenic stroke patients with and without patent foramen ovale: the PFO-ASA study: atrial septal aneurysm. *Stroke* 2002;33:706–11.
434. Mojadidi MK, Zaman MO, Elgendy IY, et al. Cryptogenic stroke and patent foramen ovale. *J Am Coll Cardiol* 2018;71:1035–43.
435. Handke M, Harloff A, Olschewski M, Hetzel A, Geibel A. Patent foramen ovale and cryptogenic stroke in older patients. *N Engl J Med* 2007;357:2262–8.
436. Bannan A, Shen R, Silvestry FE, Herrmann HC. Characteristics of adult patients with atrial septal defects presenting with paradoxical embolism. *Catheter Cardiovasc Interv* 2009;74:1066–9.
437. Papa M, Gaspardone A, Fracasso G, et al. Usefulness of transcatheter patent foramen ovale closure in migraineurs with moderate to large right-to-left shunt and instrumental evidence of cerebrovascular damage. *Am J Cardiol* 2009;104:434–9.
438. Tobis JM, Charles A, Silberstein SD, et al. Percutaneous closure of patent foramen ovale in patients with migraine: the PREMIUM trial. *J Am Coll Cardiol* 2017;70:2766–74.
439. Shah R, Nayyar M, Jovin IS, et al. Device closure versus medical therapy alone for patent foramen ovale in patients with cryptogenic stroke: a systematic review and meta-analysis. *Ann Intern Med* 2018;168:335–42.
440. Wintzer-Wehekind J, Alperi A, Houde C, et al. Long-term follow-up after closure of patent foramen ovale in patients with cryptogenic embolism. *J Am Coll Cardiol* 2019;73:278–87.
441. Mas JL, Arquizan C, Lamy C, et al. Recurrent cerebrovascular events associated with patent foramen ovale, atrial septal aneurysm, or both. *N Engl J Med* 2001;345:1740–6.
442. Oster MA, Bhatt AB, Zaragoza-Macias E, Dendukuri N, Marelli A. Interventional therapy versus medical therapy for secundum atrial septal defect: a systematic review (Part 2) for the 2018 AHA/ACC guideline for the management of adults with congenital heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol* 2019;73:1579–95.

443. Hörer J, Müller S, Schreiber C, et al. Surgical closure of atrial septal defect in patients older than 30 years: risk factors for late death from arrhythmia or heart failure. *Thorac Cardiovasc Surg* 2007;55:79–83.
444. Gatzoulis MA, Freeman MA, Siu SC, Webb GD, Harris L. Atrial arrhythmia after surgical closure of atrial septal defects in adults. *N Engl J Med* 1999;340:839–46.
445. Ghosh S, Chatterjee S, Black E, Firmin RK. Surgical closure of atrial septal defects in adults: effect of age at operation on outcome. *Heart* 2002;88:485–7.
446. An G, Zhang H, Zheng S, Wang W, Ma L. Mid-term outcomes of common congenital heart defects corrected through a right subaxillary thoracotomy. *Heart Lung Circ* 2017;26:376–382.
447. Stout KK, Daniels CJ, Valente AM, et al. 2018 AHA/ACC guideline for the management of adults with congenital heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol* 2019;73:1494–563.