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2-year results of the ISAR-ABSORB registry. J Am Coll Cardiol Intv, 10, 1222–9. Wijeysundera HC, et al. (2013). Coronary artery bypass graft surgery vs percutaneous interventions in coronary revascularization: a sys- tematic review. JAMA, 310, 2086–95. 16.13.6 Coronary artery bypass and valve surgery Rana Sayeed and David Taggart ESSENTIALS Coronary artery bypass grafting (CABG)—the two main indications are relief of symptoms, usually angina and/or breathlessness, that persist even with optimal medical therapy, and/or prognosis. There is a prognostic benefit for CABG in patients with large volumes of ischaemia (i.e. affecting >12% of the ventricular myocardium), and the benefit of revascularization increases with increasing volumes of ischaemia. The overall mortality for elective CABG in the United Kingdom is around 1% and has fallen steadily over the last decade despite an increasingly adverse risk profile of patients undergoing surgery. In randomized trials and large propensity-matched cohort registries, CABG—in comparison to percutaneous coronary inter- vention, even with drug-eluting stents—has been shown to improve survival and to reduce the subsequent risk of myocardial infarction and recurrent angina. Approximately 80% of patients are alive a decade after surgery, of whom around 70% are still free from angina. Valve surgery—this is primarily performed for patients with severe valvular disease and symptoms. Indications also include deteriorating ventricular function and the requirement for coronary artery sur- gery in patients with coexistent valve disease. Mitral valve repair is a highly successful procedure in patients with nonrheumatic valvular regurgitation and is associated with an excellent long-term survival. Aortic valve disease is usually treated with aortic valve replacement. A range of biological and mechanical valves are available for valve surgery, with no difference in outcomes between mechanical and biological valves with respect to mortality, prosthetic valve endocar- ditis, or thromboembolism, but biological valves have a higher rate of reoperation, and the haemodynamic profiles of biological and newer mechanical valves are similar. Biological valves are particularly attractive for elderly patients in whom anticoagulation is deemed high risk, and are now the commonest type of valve implanted worldwide. Patients with aortic stenosis may also be considered for transcatheter valve implantation when the risks of conventional sur- gery are high or prohibitive. The indications for transcatheter valve implantation for aortic stenosis, and for mitral regurgitation, are likely to expand significantly as these techniques develops.

16.13.6 Coronary artery bypass and valve surgery 3667 Introduction Valve surgery was developed in the 1920s for the treatment of con- genital heart disease and mitral stenosis. The development of durable valve prostheses in the 1950s allowed surgery for a wider range of ac- quired valvular heart disease. Currently, degenerative disease–causing aortic stenosis, aortic regurgitation, and mitral regurgitation is preva- lent in North America and Europe; rheumatic heart disease remains a significant cause of valvular stenosis and/or regurgitation elsewhere. Every year, over 13 000 valve procedures are performed in the United Kingdom and almost 100 000 in the United States of America. Coronary artery bypass grafting (CABG) has now been per- formed for over half a century and it is estimated that approxi- mately three-quarters of a million such operations are performed worldwide annually. Over the last decade the numbers of CABG operations have fallen in most developed countries because of im- proved medical therapy and advances in percutaneous coronary intervention (PCI), while the numbers of CABG operations con- tinue to increase in the developing world. Attempts to improve the blood supply to the heart through in- direct means were first attempted over a century ago. However, it was technological advances in the 1960s that allowed direct suturing of either the internal thoracic artery or saphenous vein grafts to the native coronary artery that led to dramatic improvements in the relief of angina and the explosive growth in CABG surgery. The publica- tion of randomized trials comparing CABG to medical therapy in the 1970s demonstrated the superior efficacy of CABG in relieving an- gina, and a subsequent meta-analysis of these trials also reported that CABG resulted in a survival benefit over a 10-year follow-up period. This led to further dramatic increases in the number of CABG oper- ations in developed countries over the following two decades. Initially, most CABG operations were performed using saphe- nous vein graft conduits, but the demonstration of superior patency and clinical outcomes with an internal thoracic artery graft eventu- ally resulted in most patients receiving an internal thoracic artery graft to the anatomically and functionally most important coronary artery, the left anterior descending artery. The superior angiographic patency of the internal thoracic artery in comparison to vein grafts is largely explained by the tendency to develop intimal hyperplasia and atherosclerosis in vein grafts, a pathological process from which the internal thoracic artery remains largely immune. Over the last decade there have been attempts to promote the use of more arterial grafts during multivessel CABG surgery, and particularly the use of both internal thoracic arteries. Although earlier meta-analyses suggested an improved survival benefit for bilateral versus single internal thoracic artery use, the Arterial Revascularization Trial (ART) found no significant difference be- tween CABG patients receiving single internal thoracic artery grafts and those receiving bilateral grafts with regard to mortality or the rates of cardiovascular events at ten years of follow-up on an inten- tion to treat analysis. However, interpretation of ART is complicated by the fact that 40% of patients received a different treatment from that initially proposed. In an as-treated analysis of patients receiving at least two arterial grafts there was a strong survival advantage and marked reduction in cardiovascular events at 10 years. A separate post hoc analysis of the ART cohort showed that an additional ra- dial artery graft was associated with lower risk for mid-term major adverse cardiac events in both single and bilateral internal thoracic artery groups. The use of a third arterial conduit in CABG surgery is associated with superior long-term survival, irrespective of gender and diabetic mellitus status. Over the last two decades there has also been considerable enthu- siasm for the use of off-pump CABG to avoid the deleterious effects of cardiopulmonary bypass, but recent large trials have shown no difference in clinical outcome for most patients whether CABG sur- gery is performed on or off pump. General considerations in assessing patients for cardiac surgery The decision to proceed to cardiac surgery involves a careful assess- ment of the operative risk. In an ageing population with multiple

comorbidities these considerations become increasingly important and significantly influence the decision to intervene and the choice between surgery and percutaneous or transcatheter intervention. The presence of significant comorbidity has more importance when surgery is being performed for prognostic rather than symptom- atic grounds. In some patients, long-term prognosis is determined to a greater degree by their comorbidity than by their coronary or valvular disease, and in those who have asymptomatic disease the benefits of intervention have to be carefully weighed against the risks. All patients will have routine haematological and biochemical assessment, coronary angiography, and echocardiography. Patients undergoing valve surgery should have a dental assessment including a panoramic radiograph. Angiographic assessment can be refined by the use of pressure wire studies, particularly in those cases where the presence of a given coronary stenosis will determine the choice be- tween PCI and surgery. In patients in whom coronary bypass surgery is being performed for prognostic benefit, in particular those with significant left ventricular impairment, assessment with myocardial perfusion imaging or MRI will guide the decision to revascularize based on the extent of viable myocardium and reversible ischaemia. Right heart catheterization may be required in the assessment of mi- tral valve disease or where significant pulmonary hypertension has been identified on echocardiography. Antiplatelet therapy with the exception of aspirin should be with- drawn in patients undergoing elective surgery (see Box 16.13.6.1). Box 16.13.6.1 Management of antiplatelet therapy before coronary artery bypass grafting surgery • Assessment of the risk of bleeding and ischaemia is recommended when making the decision for CABG surgery • Low-dose aspirin (75–160 mg daily) should be maintained in patients undergoing CABG surgery • In patients with increased bleeding risk and in those who refuse blood transfusion, cessation of aspirin 3–5 days before surgery is re- commended based on individualized assessment of ischaemic and bleeding risks • In patients on P2Y12 inhibitors it is recommended to postpone surgery for 5 days after interruption of ticagrelor or clopidogrel, and 7 days for prasugrel, unless the patient is at high risk of ischaemic events Adapted from Sousa-Uva M, et al., on behalf of ESC Working Group on Cardiovascular Surgery and ESC Working Group on Thrombosis (2013). Expert position paper on the management of antiplatelet therapy in patients undergoing coronary artery bypass graft surgery. Eur Heart J, 10, 1093.

section 16 Cardiovascular disorders 3668 Several scoring systems have been developed to estimate the risks of cardiac surgery. Meanwhile, in the EuroSCORE II, a number of parameters have been identified on univariate analysis to influence the outcome of surgery as shown in Table 16.13.6.1. The operative mortality in elderly patients has fallen substantially over the past 30 years and it is no longer unusual to consider sur- gery in patients over the age of 80 if their overall risk is acceptable. The risk of coronary artery bypass surgery in patients over the age of 85 is approximately 9% compared to less than 1% in those aged 60 or under; the corresponding figures for isolated valve surgery are 7% and 2.6% respectively. The risks are substantially affected by comorbidities such as chronic obstructive airways disease, cerebro- vascular disease, and renal disease, which are more common in this age group. Frailty, though increasingly important, is difficult to de- fine and is probably best assessed by an experienced physician re- viewing the patient, although attempts have been made to develop a frailty index to assist in decision-making. Moderate to severe chronic obstructive airways disease (i.e. FEV1/ FVC <0.7 and FEV1 <80% predicted) increases surgical mortality threefold and if combined with a DLCO of less than 50% the mor- tality increases tenfold. Many patients with chronic obstructive pulmonary disease (COPD) are wrongly classified prior to cardiac surgery and routine pulmonary function testing in patients with a smoking history or history of COPD is advised. Carotid artery disease is associated with an

increased risk of stroke during cardiac surgery; however, there is no evidence that routine screening of all patients is required. Screening of patients aged over 70 with an additional risk factor (carotid bruit, history of cerebro- vascular disease, diabetes mellitus, or peripheral vascular disease) is probably justified. Intervention for carotid disease should be con- sidered at or before surgery in patients with a history of cerebrovas- cular disease and a carotid stenosis (50–99% in men and 70–99% in women). The role of carotid surgery in asymptomatic patients is controversial but it should be considered in men with bilateral se- vere carotid stenosis or contralateral occlusion if the operative com- plication rate for carotid surgery is low and life expectancy is good. The 30-day mortality of patients with acute renal failure in the postoperative period approaches 60% in some series. The risk is largely dependent on the baseline creatinine clearance (see Fig. 16.13.6.1). Cardiac surgery in patients on dialysis carries a threefold greater mortality and patients are more likely to suffer a stroke, pneumonia, or sepsis in the postoperative period. There is some evidence that off-pump bypass surgery reduces the risks of surgery in this group of patients. The decision to proceed to cardiac surgery involves a multidis- ciplinary team of cardiologists, surgeons, and physicians, and de- tailed preoperative assessment is required for an informed decision to be made. Coronary artery bypass surgery Indications Indications for revascularization by either PCI or CABG are shown in Table 16.13.6.2. The major indications for CABG are the relief of angina or breathlessness in patients who remain symptomatic despite optimal medical therapy and for prognosis in patients with Table 16.13.6.1 Variables associated with mortality for cardiac surgery (EuroSCORE II) Patient-related factors Cardiac-related factors Operation-related factors Age NYHA class Operative urgency (elective, urgent, emergency, or salvage) Female CCS class 4 angina Weight of intervention (isolated CABG, single non-CABG, two procedures, >2 procedures) Renal impairment Left ventricular function Surgery on the thoracic aorta Extracardiac arteriopathy Recent myocardial infarction Poor mobility Pulmonary hypertension Previous cardiac surgery Chronic lung disease Active endocarditis Critical preoperative statea Diabetes on insulin a Critical preoperative state is defined as ventricular tachycardia or fibrillation, aborted sudden death or cardiac massage, ventilation prior to surgery, inotropic support, ventricular assist device/balloon pump preoperatively or acute renal failure (anuria or oliguria <10 ml/h). Adapted from Nashef SAM, et al. (2012). EuroSCORE II. Eur J Cardiothorac Surg, 41, 734–45. 5 0

> 100 <40 40–60 60–80 Creatinine clearance 80–100 1 2 3 Risk of acute rental failure (%) 4 Fig. 16.13.6.1 Risk of acute renal failure according to baseline creatinine clearance. From Chertow GM, Lazarus JM, Christiansen CL, Cook EF, Hammermeister KE, Grover F, Daley J (1997). Preoperative renal risk stratification. Circulation, 95(4), 878–84.

 substantial volumes of ischaemia (classified as involving >12% of the ventricular myocardium). Recent guidelines published in Europe and North America broadly agree that there is a prognostic advantage of CABG in pa- tients with the most severe coronary artery disease and particularly in the presence of complex three-vessel disease and/or left main dis- ease. Revascularization is also indicated in patients with impaired left ventricular function and severe coronary artery disease and es- pecially with the demonstration of significant ischaemia and viable myocardium. Non-ST-elevation myocardial infarction Patients with non-ST-elevation myocardial infarction often require urgent

revascularization by either PCI or CABG. For isolated one- or two-vessel disease, and particularly where the culprit lesions are not complex, PCI is an appropriate strategy. In contrast, for those patients with complex multivessel coronary artery disease CABG is still the preferred treatment option soon after medical stabilization of the patient using optimal medical therapy. ST-elevation myocardial infarction There is universal agreement that the primary treatment of ST- elevation myocardial infarction is immediate PCI, preferably within 90 min. There is a prohibitively high risk for CABG surgery in patients with acute myocardial infarction. CABG is therefore reserved for patients who exhibit persistent symptoms or evidence of ischaemia despite PCI or who become haemodynamically un- stable, and those who develop mechanical complications of myo- cardial infarction such as papillary muscle rupture or ventricular septal defect. The CABG operation Most CABG operations are performed through a median sterno tomy, which allows excellent access to all anatomical regions of the heart. In certain situations, CABG can be performed through a minithoracotomy, with or without the aid of robotic instruments. After median sternotomy one or both internal thoracic arteries are harvested, while the saphenous vein from the lower limb and/ or the radial artery from the forearm may also be harvested sim- ultaneously as additional conduits. The left internal thoracic artery remains attached proximally to the subclavian artery, and the right internal thoracic artery can either remain in situ or be anastomosed as a composite graft to the left internal thoracic artery. Around 80% of all CABG operations are completed using cardio- pulmonary bypass by draining venous blood from the right atrium into the extracorporeal perfusion circuit, where it is oxygenated and cooled, and then returning it to the ascending aorta so that the heart and lungs are effectively bypassed. A large clamp is then placed across the ascending aorta and a cardioplegia solution— usually either crystalloid or blood containing a high concentration of potassium—is used to arrest the heart to provide the surgeon with a motionless, bloodless operating field. After completion of the distal anastomoses the aortic clamp is removed so that the heart is reperfused while the proximal end of the radial artery or vein graft is sewn to the ascending aorta after isolating part of the as- cending aorta with a side-biting clamp. If the operation is performed off pump (without the use of car- diopulmonary bypass) a stabilizing device is used to immobilize a small area of the heart to allow the anastomosis to be performed to the coronary artery. Outcomes The 10-year survival for a patient following a standard CABG operation using internal thoracic artery and saphenous vein grafts is expected to be in the region of 80%. Half of late deaths are due to vein graft failure, which has been a driving force for increasing the use of two internal thoracic arteries. At 10 years the patency of the internal thoracic artery is around 95% in comparison to about 50% for vein grafts. Recent studies have shown that the patency of the internal thoracic artery remains at over 90% two decades after follow-up. In younger patients there is general agreement to try to maximize the use of internal thoracic arteries and radial arteries because of their improved patency over the longer term. There is evidence that use of two internal thoracic arteries improves survival and freedom from further interventions in comparison to a single internal thor- acic artery. Similarly, there is increasing evidence that the more frequent use of arterial grafts also reduces rates of myocardial in- farction and recurrent angina. Secondary prevention The use of secondary prevention is mandatory in patients who have undergone any revascularization whether by PCI or CABG. Minimum therapy should be at least one antiplatelet medication, β-blockers, statins, and angiotensin-converting enzyme inhibitors in the presence of impaired left ventricular function. The choice between CABG and PCI There is strong evidence from randomized trials such as SYNTAX and FREEDOM (in diabetic patients), and from several large-scale Table 16.13.6.2 Indications for revascularization in stable angina or silent ischaemia Subset of coronary disease by anatomy Evidence class For prognosis Left main stem

stenosis >50% IA Any proximal LAD stenosis >50% IA Two-vessel or three-vessel disease with stenosis >50% with impaired LV function (LVEF ≤35%) IA Large area of ischaemia (>10% LV or abnormal fractional flow reserve) IB Single remaining patent coronary artery with >50% stenosis IC For symptoms Any stenosis >50% with limiting angina or angina equivalent unresponsive to optimal medical treatment IA CHF, chronic heart failure; LAD, left anterior descending artery; LV, left ventricle. The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) (2014). Guidelines on myocardial revascularization. Eur Heart J, 35, 2541–619.

section 16 Cardiovascular disorders 3670 propensity-matched registries with tens of thousands of patients, of a persistent survival advantage of CABG by around 5%, 3 to 5 years after intervention. In patients with the most severe dis- ease the difference in survival in favour of CABG is around 10%. These survival curves continue to diverge with further duration of follow-up, suggesting that over the longer term the benefits of CABG may be even greater. This difference between CABG and PCI has persisted despite advances in PCI technology from bal- loon angioplasty to bare metal stents to drug-eluting stents and to the newer generation of drug-eluting stents. The likely reason for the persistent survival advantage of CABG is that placing bypass grafts to the mid-coronary vessels makes the complexity of prox- imal coronary artery disease irrelevant and protects against the development of new proximal disease, which is still common des- pite optimal medical therapy. In contrast, PCI can only deal with localized proximal culprit lesions and has no prophylactic benefit against the development of new disease. Heart valve surgery Indications The indications for valve surgery are covered in more detail else- where (see Chapter 16.6). In brief, surgery is indicated for symp- tomatic (breathlessness, angina, syncope) severe valvular disease or for asymptomatic severe valvular disease with evidence of patho- physiological changes (e.g. abnormal exercise test for asymptom- atic severe aortic stenosis, left ventricular dysfunction, pulmonary hypertension, or atrial fibrillation for asymptomatic severe mitral regurgitation). Repair or replacement The suitability and success of valve repair rather than replace- ment depends on valve pathology, the pathophysiological conse- quences, and surgical expertise. The advantages of valve repair are the avoidance of anticoagulation, prosthetic valve dysfunction, and paravalvular leak, with lower procedural risks and better long-term outcome. Techniques for mitral valve repair for degenerative disease are well established with excellent long-term outcomes with respect to reoperation. More than 90% of degenerative mitral valves are suit- able for repair using a combination of techniques: resection or pli- cation of prolapsing or redundant leaflet tissue; chordal replacement with expanded polytetrafluoroethylene neochords; or annuloplasty, usually with implantation of a prosthetic ring or band to support the repair and prevent further annular dilatation. The cumulative reoperation rate is less than 1%/year, better for isolated posterior leaflet repair (0.5%), and worse for bileaflet (0.9%) or anterior leaflet (1.6%) repairs. Current guidelines support early mitral valve re- pair for asymptomatic severe mitral regurgitation when there is a high expectation of successful durable repair and low procedural mortality. Surgical repair for rheumatic mitral valve disease is more limited, depending on the extent and chronicity of rheumatic changes: closed and open commissurotomy may be performed to palliate mitral stenosis. Several techniques for aortic valve repair for aortic regur- gitation in bicuspid and trileaflet valves have been described to treat cusp, commissural, and annular pathology in selected cases, but long-term outcomes are uncertain. Surgical approaches Most valve procedures are performed through a median sternotomy on cardiopulmonary bypass, as described for CABG. Several minimal- access approaches have been described that allow better cosmesis compared with median sternotomy. Aortic valve replacement

may be undertaken through a partial upper sternotomy with a J-shaped or in- verted T sternal incision through the third or fourth intercostal space, or through a right anterior thoracotomy. The mitral valve may be ap- proached through a lower partial sternotomy, right thoracotomy, or a port access approach through the right chest using a thoracoscopic camera for guidance and specialized instruments; robotic mitral valve surgical techniques have also been developed, but these are limited to specialized centres owing to the high costs of a surgical robot. Depending on the exposure, these minimal-access approaches may require peripheral cannulation for cardiopulmonary bypass, with specialized surgical equipment for venting and arresting the heart, and clamping the aorta. There is a recognized learning curve for these newer surgical approaches, and, although a shorter in-hospital stay and faster early recovery have been reported, the medium-term out- comes remain equivalent to standard open approaches. Transcatheter valve implantation Percutaneous valve intervention techniques have been developed that have replaced surgery in cases with prohibitive surgical risk. Transcatheter aortic valve implantation (TAVI) for aortic stenosis uses standard pericardial bioprosthetic valves mounted in balloon- expandable or self-expanding alloy frames, implanted through the femoral or subclavian artery, ascending aorta, or left ventricular apex, depending on the type of device, presence of vascular disease, and institutional expertise. The procedural success rate is 95% with a 90% or lower 30-day mortality and lower than 2% stroke rate. TAVI is re- commended for inoperable patients (logistic EuroSCORE ≥ 20, STS PROM ≥ 8) following the PARTNER B study that found a significant reduction in 2-year all-cause mortality with TAVI compared with optimal medical therapy in inoperable severe aortic stenosis (43.3% vs. 68%). The PARTNER A study found TAVI to be non-inferior to surgical aortic valve replacement with respect to 2-year all-cause mortality (33.9% vs. 35%) in a high-risk surgical cohort (STS pre- dicted mortality ≥10). TAVI devices for aortic regurgitation have not yet been widely introduced. Further improved devices are under development to facilitate intraprocedural positioning and to reduce the risks of acute coronary ostial occlusion and paravalvular leak. Transcatheter mitral valve devices are also coming into clinical prac- tice. The MitraClip (Abbott Vascular) has an established role for edge-to-edge mitral valve repair in symptomatic mitral regurgitation patients at prohibitive or high surgical risk, and novel percutaneous mitral valve replacement devices are under development. Types of valve prosthesis Biological valves Biological or bioprosthetic valves may be xenografts, homo- grafts (allografts), or autografts. Xenograft valves are made from glutaraldehyde-fixed animal leaflet tissue with a proprietary anticalcification treatment, most commonly bovine pericardium or

 porcine aortic valve mounted in an alloy frame for a stented valve, or a whole porcine aortic root for a stentless prosthesis. The advan- tages of stented xenograft valves are the ease of implantation, the avoidance of long-term anticoagulation, and the ease of reoperation; the development of transcatheter valve-in-valve implantation offers an additional less invasive option. Porcine stentless valves became popular in the 1990s because of their excellent haemodynamics and avoidance of long-term anticoagulation; however, these valves are more challenging to implant reliably, either as a subcoronary im- plant or as a mini-root replacement, and the rate of structural valve deterioration is higher than for stented valves. Homografts (allografts) are antibiotic-treated cryopreserved cadav- eric grafts including the aortic root and valve. Homografts are resistant to infection and are used for aortic root replacement, particularly for aortic valve endocarditis, in younger patients to avoid the need for anticoagulation, and where there is extensive periannular infection and tissue destruction to allow left ventricular outflow tract reconstruction. However, although the durability at 10 years is

similar to pericardial bioprosthetic valves, the reoperation rate for structural valve deterior- ation at 15 years is as high as 20% in patients aged 41–60 years, and reoperation is challenging owing to homograft calcification. Finally, the Ross procedure, described in 1962, uses a pulmonary autograft for aortic root replacement with the pulmonary outflow tract replaced with an aortic homograft. The pulmonary autograft is viable tissue and is able to grow in young patients, has excellent haemodynamics with a low thromboembolic risk, and is resistant to infection. The complexity of the Ross procedure limits its use to specialist centres for selected cases (e.g. women of childbearing age keen to avoid anticoagulation). The Ross procedure is complicated by homograft stenosis in 10 to 20% and aneurysmal dilatation of the autograft causing aortic regurgitation; the 10-year structural valve deterioration rate is up to 30%. ‘Sutureless’ or rapid-deployment valves are bioprosthetic aortic valves incorporating many features of transcatheter valves, to allow faster implantation in the debrided aortic annulus after open sur- gical resection of the diseased valve. Cardiopulmonary bypass and cardioplegic arrest are still required, but these valves facilitate min- imally invasive approaches and allow shorter procedural times, al- though the longer-term benefits have yet to be confirmed. Mechanical valves Mechanical valves offer the advantage of excellent durability but the disadvantages of long-term anticoagulation and the risks of bleeding; modern low-profile valves have better haemodynamic properties and lower thromboembolic risk than earlier gener- ations. The PROACT study is comparing standard anticoagulation against lower intensity anticoagulation for high thromboembolic risk cases and dual antiplatelet therapy for low-risk cases with the On-X bileaflet valve: early results are encouraging, with a 0.6%/year thromboembolic event rate and 0.4%/year significant bleeding rate. Meta-analyses of the randomized studies comparing mechanical with biological valves have found no difference in outcomes between mechanical and biological valves with respect to mortality, pros- thetic valve endocarditis, or thromboembolism; biological valves have a higher rate of reoperation, mechanical valves a higher risk of significant bleeding complications. The Veterans Administration study found a better 15-year survival for mechanical valves, but the Edinburgh Heart Valve trial found no difference in survival at 20 years. The choice of valve prosthesis for an individual patient de- pends on several factors including, most importantly, the wishes of the patient, age and life expectancy, metabolic factors predisposing to calcification and early structural valve deterioration (e.g. chronic kidney disease), any contraindication to anticoagulation, expect- ation of pregnancy, previous infection, and risk of reoperation. There has been a steady increase in the proportion of biological valves im- planted over the last decade with these valves now making up more than 80% of valves implanted. Anticoagulation Anticoagulation for prosthetic valves Anticoagulation is required for all currently available mechanical valves. The intensity of anticoagulation depends on valve char- acteristics and its position, and patient factors such as a history of thromboembolism, atrial fibrillation, left atrial enlargement, and left ventricular dysfunction. Current recommendations for anticoagulation are summarized in Box 16.13.6.2. Management of anticoagulation for noncardiac surgery Anticoagulation is usually stopped for noncardiac surgery depending on the prosthesis type and bleeding risk of sur- gery. Patients with modern bileaflet or tilting disc mechanical aortic valves at low risk of thromboembolism and with no risk Box 16.13.6.2 Guidelines for choice of prosthetic heart valve Guidelines favouring bioprosthetic valves ECS/EACTS 2017 guidelines Anticoagulation contraindicated, unavailable, or unable to be managed appropriately Class IC Patient preference Class IC Reoperation for mechanical valve thrombosis despite good long-term anticoagulation Class IC Women of childbearing age contemplating pregnancy Class IIaC Low risk for future redo valve replacement Class IIaC A bioprosthesis should be considered in those aged >70 years (>65 years for aortic valve replacement in European guidelines) Class IIaC Guidelines favouring

mechanical valves ECS/EACTS 2017 guidelines Informed patient preference Class IC Accelerated risk of structural valve deterioration (age <40 years, hyperparathyroidism) Class IC Patient already on anticoagulation for a mechanical valve in another position Class IIaC Reasonable life expectancy (>10 years) and high risk for future repeat valve replacement Class IIaC A mechanical prosthesis is reasonable for those aged <60 years (<65 years for mitral valve replacement in European guidelines) Class IIaC Patient already on anticoagulation due to high risk of thromboembolism (atrial fibrillation, venous thromboembolism, thrombophilia, severe left ventricle dysfunction) Class IIbC

section 16 Cardiovascular disorders 3672 factors such as atrial fibrillation, history of thromboembolism or hypercoagulability, or left ventricular dysfunction, may stop war- farin 3 to 5 days before surgery, with no need for bridging therapy with low molecular weight or unfractionated heparin. In all other cases, bridging therapy is indicated before and after surgery for an INR of 2.0 or less; heparin should be resumed after surgery as soon as the immediate risk of bleeding has passed. Excessive anticoagulation Anticoagulation may need to be reversed because of an excessive INR, for bleeding, or for emergency surgery. Prothrombin com- plex concentrate is recommended for rapid reversal for bleeding. A mildly elevated INR with no signs of bleeding may be managed by the omission and/or adjustment of warfarin doses. Oral vitamin K and omission of warfarin are recommended for the correction of a higher INR with no bleeding. Complications of cardiac surgery Operative mortality The overall mortality for all CABG in the United Kingdom is around 1.8%, being just under 1% for elective CABG and approximately 2% for all urgent CABG. Overall mortality has remained low des- pite an increasing risk profile in patients who are ever more elderly with significant comorbidities. Valve surgery caries a slightly higher risk: the mortality rates for uncomplicated mitral valve repair and aortic valve replacement are approximately 2%. A consistently low mortality almost certainly reflects improvements in medical man- agement of patients as well improvements in anaesthetic, surgical, and perfusion techniques. Neurological injury Significant neurological injury is arguably the most feared compli- cation of cardiac surgery and occurs with an incidence of around 1 to 2% during surgery or in the perioperative period. Of patients with neurological injury approximately one-third will die, one-third will remain severely disabled, and one-third will make a good recovery. The incidence of stroke is statistically higher in patients with left main disease than those with isolated three-vessel disease and this may reflect a concomitant higher burden of carotid artery disease in patients with left main disease. The major risk factors for stroke are advanced age, significant disease of the ascending aorta, carotid artery disease, previous neurological injury, and the development of postoperative atrial fibrillation. There is strong evidence that CABG performed off pump using a no-touch aortic technique is the best surgical methodology for reducing incidence of stroke. Sternal wound complications Sternal wound dehiscence is another particularly troublesome complication of median sternotomy. The overall incidence is around 0.6% and the main risk factor is insulin-dependent dia- betes, especially in combination with obesity. In such patients the use of two internal thoracic arteries leads to a small but significant increase in this risk of sternal dehiscence, and is therefore gen- erally avoided. The treatment of sternal dehiscence is prolonged, complex, and miserable for all parties, usually requiring a period of vacuum-assisted dressings followed by plastic surgical reconstruc- tion with muscle flaps. Pleural effusion Pleural effusions are usually small and self-limiting and easily treated by chest drainage. They may also develop after patient dis- charge as a late event. Pericardial effusion All patients develop pericardial effusions after cardiac surgery and in the vast majority these are self-limiting and require no specific therapy.

A small percentage of patients may develop significant peri- cardial effusions which can usually be drained by a small incision under the xiphisternum or by using a thoracoscope through the pleural cavity and the pericardium. Pericardial effusions can also appear after patient discharge and can usually be drained without having to reopen the full sternotomy. Atrial fibrillation Atrial fibrillation occurs temporarily in around 30% of patients after CABG and the incidence may be reduced by peri-and postoperative β-blockade. It is now standard practice to anticoagulate these pa- tients as well as treat with amiodarone for 6 weeks. If the patient remains in atrial fibrillation after this period, then cardioversion is indicated. Conduction defects Cardiac conduction defects are common after valve surgery, par- ticularly aortic valve replacement owing to the proximity of the atrioventricular node and bundle of His to the right coronary– noncoronary commissure: conduction pathways may be damaged during valve debridement, by direct injury from a suture, or by postoperative oedema. First-degree or higher degrees of heart block are common after aortic valve surgery and most surgeons routinely place epicardial atrial and ventricular pacing wires for temporary postoperative pacing. Complete heart block requiring implantation of a permanent pacemaker is needed in 3 to 8% of aortic valve re- placement cases, being more common in older people, with pre- existing conduction defects, and in valve surgery. Structural valve deterioration Acute primary valve failure is rare in current mechanical or bio- logical valves, but emergent or urgent reoperation is indicated. Structural valve deterioration is a complication of biological valves owing to leaflet fibrosis and calcification causing progressive valvular stenosis, and perforation and leaflet tearing leading to re- gurgitation. Structural valve deterioration develops at a predictable rate related to younger patient age, valve position, mitral more af- fected than aortic, altered calcium metabolism (e.g. chronic kidney disease), and pregnancy. Pericardial valves deteriorate more slowly than porcine bioprostheses. The indications for reoperation for structural valve deterioration are the same as for native valve dis- ease, based on symptoms, ventricular size and function, and pul- monary hypertension. Thromboembolism The incidence of clinical thromboembolic events is up to 2.3 cases per 100 patient-years. The risk is similar for biological and

16.13.6 Coronary artery bypass and valve surgery 3673 anticoagulated mechanical valves. Risk factors for thrombo- embolism include prosthesis type and position, a history of thromboembolism or hypercoagulability, atrial fibrillation and left atrial size, and left ventricular dysfunction. Thromboembolism with a mechanical valve is managed by ensuring that the INR is in the therapeutic range, or if the INR is already therapeutic, by increasing the target INR or adding low-dose aspirin. Prosthetic valve thrombosis Thrombosis of a mechanical valve may be a life-threatening com- plication. The diagnosis is suggested by heart failure, signs of a low cardiac output, or thromboembolism with reduced or absent pros- thetic valve sounds, new murmurs, or documented inadequate anticoagulation. Mitral and tricuspid valves are more commonly in- volved. Echocardiography or fluoroscopy usually confirm reduced leaflet or disc motion caused by an occluding thrombus. Emergency reoperation is recommended for left-sided valve thrombosis with shock or New York Heart Association (NYHA) III or IV symptoms or cases with large thrombi (>0.8 cm2 on transoesophageal echocardi- ography (TOE)) but the operative mortality is up to 30%. Fibrinolysis with tPA or streptokinase may be used for left-sided valves with less severe symptoms (NYHA I and II) or smaller thrombus burdens and for patients unsuitable for reoperation; fibrinolysis is recommended for right-sided valve thrombosis. Fibrinolysis for left-sided valve thrombosis is associated with a 15–20% risk of systemic embolism or death. Prosthetic valve endocarditis Prosthetic valve endocarditis (PVE) is more common early after surgery, with an incidence up to 3% at 1 year. Mechanical valves are more commonly involved over the first year,

but the incidence for mechanical and biological valves is similar thereafter. Early PVE (within 1 year) in most commonly due to nosocomial coagulase- negative staphylococci; late PVE (after 1 year) is caused by a similar range of organisms as native valve endocarditis. PVE fol- lows a more aggressive course than native valve endocarditis with early perivalvular tissue destruction and abscess formation. TOE is important to establish the diagnosis and identify complications indicating early surgery. Medical therapy is usually ineffective in PVE. Early surgery is recommended for heart failure, abscess for- mation, valve dehiscence or other dysfunction, or infection with a resistant organism; surgery is also indicated for a persistent bacter- aemia despite adequate antibiotic therapy or recurrent embolism from vegetations. The operative mortality for early surgery for PVE is up to 35%. Paravalvular leak A paravalvular leak may develop because of poor surgical technique, suture dehiscence, poor native tissue strength, and infection: PVE must always be excluded in the setting of a new paravalvular leak. A small leak may cause a haemolytic anaemia due to mechanical red cell damage; iron and folic acid supplements may be beneficial. Reoperation is indicated for heart failure, a persistent need for trans- fusion, or an impaired quality of life. Large leaks, particularly mitral, may cause volume overload: the development of intractable heart failure is an indication for reoperation. Catheter-based approaches may be helpful to avoid redo surgery. FURTHER READING Bonow RO, et al. (2016). Management strategies and future challenges for aortic valve disease. Lancet, 387, 1312–23. Falk V, et al. (2017). 2017 ESC/EACTS Guidelines for the manage- ment of valvular heart disease. European Journal of Cardio-thoracic Surgery, 52, 616–64. Gaudoni M, et al. (2017). Three arterial grafts improve late survival: a meta-analysis of propensity-matched studies. Circulation, 135, 1036–44. Head SJ, et al. (2017). Current practice of state-of-the-art coronary revascularisation. Circulation, 136, 1331–45. Iqbal J, et al. (2013). Optimal revascularization for complex coronary artery disease. Nat Rev Cardiol, 10, 635–47. Mohr FW, et al. (2013). Coronary artery bypass graft surgery versus percutaneous coronary intervention in patients with three-vessel disease and left main coronary disease: 5-year follow-up of the ran- domised, clinical SYNTAX trial. Lancet, 381, 629–38. Neumann F-J, et al. (2019). 2018 ESC/EACTS Guidelines on myocar- dial revascularization. Eur Heart J, 40, 87–165. Nishimura RA, et al. (2016). Mitral valve disease—current manage- ment and future challenges. Lancet, 387, 1324–34. Partridge JS, et al. (2012). Frailty in the older surgical patient: a review. Age Ageing, 41, 142–7. Stone GW, et al. (2016). Everolimus-eluting stents or bypass surgery for left main coronary artery disease. N Engl J Med, 375, 2223–35. Taggart DP, et al. (2019). Bilateral versus Single Internal-Thoracic- Artery Grafts at 10 Years. N Engl J Med, 380, 437–46. Taggart DP, et al. (2017). Associations between adding a radial artery graft to single and bilateral internal thoracic artery grafts and out- comes: insights from the Arterial Revascularization Trial. Circulation, 136, 454–63. Vohra HA, et al. (2013). Outcomes following cardiac surgery in pa- tients with preoperative renal dialysis. Interact Cardiovasc Thorac Surg, 18, 103–11.

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