Surgical Management of Valvular Heart Disease 2004*

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There has been remarkable success in the last three decades in terms of understanding, diagnosing and managing valvular heart disease. This has truly been a success story of the 20th century because in Dr Paul Dudley White's textbook entitled *Heart Disease* published just over 50 years ago, it was stated that "there is no specific treatment for mitral valve disease" and "there is no treatment for aortic valve disease." Twenty-five years ago, natural history studies on valvular heart disease presented a very ominous prognostic overview on the management of valvular heart disease. During the first half of the 20th century, mortality and morbidity from valvular heart disease had changed very little. The outstanding progress of the last three decades has been in understanding pathophysiological processes, development of diagnostic capabilities and development of surgical and catheter-based techniques now routinely performed by cardiovascular surgeons and cardiologists. The advances have provided patients the promise of improved quality of life and the potential for a normal lifespan.

The progress of the past 30 years has lead to the appreciation of the importance of ventricular function in determining natural history and outcome of the disease processes and management. Diagnostic modalities have included M-mode and two-dimensional echocardiography to assess valve pathology, chamber size and ventricular function; Doppler echocardiography to evaluate severity of stenotic and regurgitant lesions and pulmonary artery pressures (PAP); and radionuclide ventriculography to assess ventricular function at rest and with exercise. The management developments have included monoleaflet and bileaflet mechanical valves, stented and stentless bioprosthetic valves, allograft (homograft) valves and autograft valves, mitral valve repair and chordal sparing mitral valve replacement (MVR) to maintain the integrity of the mitral apparatus in patients with mitral regurgitation, and combined valve replacement or repair and coronary artery bypass surgery in patients with concomitant coronary artery disease (CAD) and valvular heart disease. The use of blood cardioplegia and retrograde delivery of cardioplegia for intraoperative myocardial protection has been a significant advance. Percutaneous mitral balloon valvotomy has developed over the past decade as an effective treatment for mitral stenosis.

The aging of the population and changes in the etiology of valve disease have modified the spectrum of valvular heart disease over the last few decades in developed countries. The predominant cause of aortic stenosis in middle aged and elderly North Americans is now degenerative calcific disease rather than congenital bicuspid disease. Aortic regurgitation also occurs more frequently from degenerative diseases than from congenital defects. The predominant cause of mitral regurgitation is now mitral valve degenerative disease rather than rheumatic heart disease. Rheumatic heart disease continues to be the primary cause of mitral stenosis (MS) in the adult population but the natural history in North America is that of a

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less virulent disease than in the early part of the 20th century. It is not uncommon for symptoms of MS to present in middle age; one-third of patients requiring management are over 65 years of age.

The predictors of survival for any valve lesion are age, severity of symptoms, severity of the valvular lesion, left ventricular (LV) or right ventricular (RV) systolic dysfunction and the presence or absence of concomitant CAD. Other influential factors include atrial fibrillation and pulmonary hypertension in mitral valve disease, degree of LV dilation in mitral or aortic regurgitation, and severity of LV hypertrophy in aortic stenosis and regurgitation.

Surgical intervention has evolved dramatically with identification of higher risk groups of patients by refinement of noninvasive methods for effective risk stratification and appropriate identification of patients, whether symptomatic or asymptomatic. Two to three decades ago, surgery was only offered to the sickest patients with the most advanced forms of valvular heart disease where there was justification for the high short and long term risks of surgery. Valve replacement or repair is now performed safely at much earlier stages of the natural history of the disease process, often in asymptomatic patients, with excellent long term results. The earlier interventions and surgical advances have completely transformed the outlook of patients with valvular heart disease.

There still remains the fundamental aspect of decision-making in patients with valvular heart disease. Valve replacement or repair is still not curative; there is only a shift in potentially serious problems and conditions. The goal is to offer surgery late enough in the natural history to justify the risks of intervention but early enough to prevent irreversible ventricular dysfunction, pulmonary hypertension or chronic arrhythmias. The risks related to natural history versus the risks related to surgery may often place the balance in favour of early intervention but one must continue to consider the anticipated early and late outcomes of surgical procedures against the expected outcome of isolated medical management.

The purpose of the Consensus Conference on Surgical Management of Valvular Heart Disease is to provide consensus for decision-making based on both objective data and sound clinical judgment.

SECTION I: EXECUTIVE SUMMARY

"Surgery of the heart has probably reached the limits set by nature to all surgery; no new method and no new discovery can overcome the natural difficulties that attend a wound of the heart."

—STEPHEN PAGET, 1896

A century later, especially within the past three decades, there has been remarkable progress in the surgical management of valvular heart disease.

The purpose of the 1999 (revision update 2004) Canadian Cardiovascular Society (CCS) Consensus Conference is to analyze and report the scientific evidence base for the surgical management of valvular heart disease, identify research issues and knowledge gaps, and recommend standards for diagnostic reporting and pathological evaluation.

The surgical management of valvular heart disease is in evolution and reaching consensus was a difficult task. The primary panel of Canadian surgeons and cardiologists brought forward different perceptions and beliefs as the document was formulated. Extensive contributions were made in formulating the document and it must remain in evolution. The secondary panel of nationally and internationally recognized surgeons and cardiologists validated the document and provided recommendations. The final 1999 version was made available for review by the membership of the CCS.

The American College of Cardiology (ACC) and American Heart Association (AHA) published the *Guidelines for the Management of Patients with Valvular Heart Disease* in late 1998. The ACC/AHA Committee on Management of Patients with Valvular Disease had the task of providing "recommendations for diagnostic testing, treatment and physical activity." The CCS primary panel incorporated the ACC/AHA guidelines where there was agreement and indicated where there was disagreement (*Circulation* granted permission to reproduce and utilize the ACC/AHA guuidelines). The CCS consensus document addresses only the surgical management of valvular heart disease but considers the overall age spectrum from the neonate to the elderly. The CCS document provides recommendations for standards of echocardiographic reporting and pathological evaluation. The document also incorporates general information, guidelines for classification of valve-related complications, prophylaxis against prosthetic valve endocarditis (PVE), antithrombotic management and recommendations for follow-up strategy for patients with prosthetic heart valves.

The recommendations are assigned classes of support and levels of evidence according to the classifications of the ACC, the AHA and the CCS.

Class I: Conditions for which there is evidence or general agreement that a given procedure or treatment is useful and effective.

Class II: Conditions for which there is conflicting evidence or a divergence of opinion about the usefulness or efficacy of a procedure or treatment.

IIa: Weight of evidence or opinion is in favour of usefulness and efficacy.

IIb: Usefulness and efficacy is less well established by evidence and opinion.

Class III: Conditions for which there is evidence or general agreement that the procedure or treatment is not useful and in some cases may be harmful.

These recommendations are based on the following levels of evidence:

Level A: The data were derived from multiple randomized clinical trials.

Level B: The data were derived from single randomized or nonrandomized studies.

Level C: The consensus opinion of experts was the primary source of recommendation.

THE CONSENSUS CONFERENCE DOCUMENT

The Consensus Conference document incorporates 15 sections.

Section I: Introduction and executive summary

The introduction summarizes the status of cardiac valvular surgery and the progress that has been made in surgical and interventional management over the past three decades. The executive summary summarizes the Class I recommendations for surgical management of valvular disease, including the research recommendations.

Section II: Research issues and knowledge gaps to increase level and/or quality of evidence

The extensive literature on valve replacement surgery unfortunately is not formulated from randomized studies. Historical retrospective and comparative studies are flawed by involuntary bias.

The primary panel has identified several general endeavours and specific areas where the Canadian community can contribute to the advancement of consensus in diagnosis and management guidelines.

The general recommendations incorporate the following endeavours:

- National Valve Data Bank, which will be an integral part of the proposed Canadian Cardiovascular Information Network;
- National Pathology Registry of explanted prostheses, which will facilitate contributions to advances in prosthesis development;
- Specific Central Registry of Results of Pulmonary Autograft Aortic Valve Replacement (AVR, which will contribute to the role of this advancing complex procedure);
- Comprehensive National Collaborative Evaluation of New Prosthetic Devices; and
- Standardization of Echocardiographic Reporting in Canada (inclusive of technical considerations, guidelines for surgical management, and short and long term surveillance).

The specific endeavours to advance the knowledge and consensus of indications for management based on comprehensive natural history evaluation are presented in section II of the consensus document.

Section III: Aortic valve, aortic root and subvalvular disease

The most common cause of valve replacement at the end of the millennium is aortic valve diseases. The aging of the population is the primary cause. Calcific aortic stenosis and aneurysm of the ascending aorta associated with valvular insufficiency are encountered in the middle aged and elderly populations.

Aortic stenosis: It is well established that asymptomatic aortic valve stenosis, even when severe, is well tolerated; however, when symptoms develop, it is important to address the issue because patient survival is significantly impacted without valve replacement. AVR in a truly asymptomatic patient with valve area less than 0.6 cm^2 and significant LV hypertrophy (greater than 1.5 mm) is still controversial. A mean gradient greater than 50 mmHg associated with a valve area less than 1.0 cm^2 is considered to be severe aortic stenosis. These parameters provide the indications for AVR in symptomatic patients. LV dysfunction (even when severe) associated with signs of severe aortic stenosis is an indication for surgery because these patients should have improved survival following AVR. Patients with a larger valve area or lower mean gradient should be assessed carefully because other etiologies could be responsible for the symptoms. In these circumstances, additional investigation is warranted.

The aortic valve should be replaced in patients undergoing coronary artery bypass or other cardiac surgery when there is moderate or severe stenosis. Mild aortic stenosis is more controversial and the experienced surgeon will prefer to explore the valve and decide during surgery if replacement is necessary.

TABLE 1
Class I recommendations for AVR in aortic stenosis

- Symptomatic patients with severe aortic stenosis;
- Patients with severe aortic stenosis undergoing coronary artery bypass surgery; or
- Patients with severe aortic stenosis undergoing surgery on the aorta or other heart valves.

The prosthesis use in AVR should be tailored to the patient. Above the age of 65 years, there is now significant evidence that a bioprosthesis should last the life of the recipient. The prosthesis choice for the younger age group is more controversial. Biological valves are more prone to failure over 10 years but carry less risk of complications than mechanical prostheses. The advantages and disadvantages should be carefully explained and the patient should participate in the decision. Stentless bioprostheses have been reported to have superior hemodynamics to stented bioprostheses, related to the ability to implant a larger size prosthesis, and should be used as an alternative to a mechanical prosthesis, especially in the small aortic root. The pulmonary autograft and the homograft should be reserved for the younger age groups. Proper surgical techniques and careful follow-up should be mandatory because long term follow-up data are limited. Aortic root replacement associated with AVR should be considered when there is significant calcification of the aortic wall. Poststenotic dilation of the ascending aorta equal to or larger than 45 mm should be addressed at the time of AVR because there is a tendency for the dilation to progress.

Aortic regurgitation: The causes of aortic regurgitation are multiple. Aortic regurgitation is well tolerated when chronic but creates an emergency situation when acute. Echocardiography is the optimal tool for diagnosis, as well as for preoperative and postoperative surveillance. Surgery is indicated when symptoms appear because the risk of death is increased significantly thereafter. The asymptomatic patient with LV dysfunction or with preserved function but progressive LV dilation, or those undergoing coronary artery bypass or other cardiac surgery should be considered for surgery.

TABLE 2
Class I recommendations for AVR in chronic severe aortic regurgitation

- Patients with New York Heart Association (NYHA) functional class III or IV symptoms and preserved LV systolic function, defined as normal ejection fraction at rest (ejection fraction 0.50);
- Patients with NYHA functional class II symptoms and preserved LV systolic function (ejection fraction 0.50 at rest) but with progressive LV dilation or declining ejection fraction at rest on serial studies or declining effort tolerance on exercise testing;
- Patients with CCS class II or greater angina with or without CAD;
- Asymptomatic or symptomatic patients with mild to moderate LV dysfunction at rest (ejection fraction 0.25 to 0.49); or
- Patients undergoing coronary artery bypass surgery or surgery on the aorta or other heart valves.

The choice of prosthesis should always be discussed with the patient. Biological prostheses are the first choice in the older age group. Biological prostheses should not be denied to the younger population. The pulmonary autograft procedure should not be considered with pure aortic regurgitation because there is evidence of progressive regurgitation of the pulmonary autograft in this population. Associated aortic root pathologies should be addressed at the time of AVR. Aortas equal to or larger than 45 mm should be considered for replacement. Composite grafts (mechanical valve conduits or stentless bioprosthetic roots), homografts or ascending aorta replacement with concomitant AVR are acceptable alternatives.

Aortic root disease: There are multiple etiologies of aortic root disease, primarily due to connective tissue disorders including medial degeneration. The aortic root disease may be primary, associated or not associated with valve pathology, or secondary to aortic valve disease. Aneurysmal formation of the aorta has a risk of rupture when the diameter is greater than 50 mm. The aneurysm should be resected because the rate of progression increases the risk of rupture. Special consideration should apply for Marfan's disease and an aggressive approach is usually warranted.

Subvalvular disease: Hypertrophic obstructive cardiomyopathy (idiopathic hypertrophic subaortic stenosis) is well treated surgically with good long term results. The alternative treatments are atrioventricular sequential pacing or alcohol injection (for muscle ablation) into the septal branch of the left anterior descending coronary artery. Surgery should be the treatment of choice in the younger population with septal ablation reserved for the older population. Subaortic stenosis can be associated with aortic valve stenosis and if present should be resected at the time of AVR. Fibrotic rings and long tubular stenosis are congenital lesions.

Section IV: Mitral valve and concomitant aortic or tricuspid disease

The most common cause of mitral stenosis is injury sustained from prior rheumatic fever. Mitral stenosis is a progressive lifelong disease but in the past decade and a half has become less virulent; symptomatic presentation is usually not until the fifth or sixth decade. There are multiple causes of chronic mitral regurgitation including degenerative disease, rheumatic heart disease and calcific annular disease of the elderly. Concomitant valve disease involving the aortic and mitral valve is usually due to chronic rheumatic disease. Concomitant tricuspid regurgitation is usually functional secondary to mitral valve disease. Ischemic mitral regurgitation may be organic with leaflet prolapse or functional with lack of coaptation of leaflets due to annular dilation and papillary muscle displacement secondary to ventricular remodelling.

The treatment options for mitral stenosis are percutaneous mitral balloon valvotomy (PMBV), mitral valve reconstruction or MVR. Balloon valvotomy is recommended for moderate or severe mitral stenosis with moderate and severe symptomatology when valve morphology is favourable and there is no atrial thrombus. Pulmonary hypertension in asymptomatic moderate or severe mitral stenosis is also an indication for valvotomy. Balloon valvotomy is contraindicated when there is moderate or severe mitral regurgitation. Mitral reconstruction is reserved for moderate or severe mitral stenosis with severe symptoms when there is persistent atrial thrombus and the mitral valve is nonpliable or calcified and unsuitable for balloon valvotomy. MVR is reserved for patients with moderate or severe mitral stenosis with severe symptoms, or mild or moderate symptoms and pulmonary hypertension when more conservative management is not considered appropriate.

TABLE 3
Class I recommendations for mitral valve repair for mitral stenosis

- Patients with NYHA functional class III to IV symptoms, moderate or severe mitral stenosis (mitral valve area [MVA] 1.5 cm^2 or less),* and valve morphology favourable for repair if PMBV is not available;
- Patients with NYHA functional class III to IV symptoms, moderate or severe mitral stenosis (MVA 1.5 cm^2 or less),* and valve morphology favourable for repair if a left atrial (LA) thrombus is present despite anticoagulation; or
- Patients with NYHA functional class III to IV symptoms, moderate or severe mitral stenosis (MVA 1.5 cm^2 or less),* and a nonpliable or calcified valve with the decision to proceed with either repair or replacement made at the time of the operation.

**The committee recognizes that there may be a variability in the measurement of MVA and that the mean transmitral gradient, pulmonary artery wedge pressure and PAP at rest or during exercise should also be considered*

TABLE 4
Class I recommendations for MVR for mitral stenosis

- Patients with moderate or severe mitral stenosis (MVA 1.5 cm^2 or less)* and NYHA functional class III to IV symptoms who are not considered candidates for percutaneous balloon valvotomy or mitral valve repair; or
- Patients with severe mitral stenosis (MVA 1 cm^2 or less)* and severe pulmonary hypertension (pulmonary artery systolic pressure greater than 60 to 80 mmHg) with NYHA functional class I to II symptoms who are not considered to be candidates for percutaneous balloon valvotomy or mitral valve repair.

**The committee recognizes that there may be variability in the measurement of MVA and that the mean transmitral gradient, pulmonary wedge pressure and PAP should also be considered*

Mechanical prosthesis should be chosen for MVR unless the patients are over 70 years of age with limited life expectancy or have accompanying comorbid disease. In the latter group of patients, bioprostheses are recommended.

Mitral regurgitation: Mitral valve surgery is recommended in acute symptomatic mitral regurgitation when repair is likely. Moderate and severe symptomatic patients with no LV dysfunction or dilation are also candidates for surgery. Symptomatic or asymptomatic patients with moderate dysfunction or increased end-systolic dimensions are also surgical candidates. On the other hand, surgery is recommended for asymptomatic patients when atrial fibrillation, pulmonary hypertension or mild to moderate ventricular dysfunction is present, and the ability to provide mitral repair is likely. The timing of surgery may be delayed in these patients when replacement is more likely to be necessary.

TABLE 5
Class I recommendations for mitral valve surgery in nonischemic severe mitral regurgitation

- Acute symptomatic mitral regurgitation in which repair is likely possible;
- Patients with NYHA functional class II, III or IV symptoms with normal LV function defined as ejection fraction greater than 0.60 and end-systolic dimension less than 45 mm;
- Symptomatic or asymptomatic patients with mild LV dysfunction, ejection fraction 0.50 to 0.60, and end-systolic dimension 45 to 50 mm;

Continued on next page

Table 5 *continued*

- Symptomatic or asymptomatic patients with moderate LV dysfunction, ejection fraction 0.30 to 0.50, or end-systolic dimension 50 to 55 mm;
- Asymptomatic patients with preserved LV function and atrial fibrillation (recent onset)*;
- Asymptomatic patients with preserved LV function and pulmonary hypertension (pulmonary artery systolic pressure greater than 50 mmHg at rest, or greater than 60 mmHg with exercise)*; or
- Asymptomatic patients with ejection fraction 0.50 to 0.60 and end-systolic dimension less than 45 mm, and asymptomatic patients with ejection fraction greater than 0.60 and end-systolic dimension 45 to 55 mm*.

**Class I if mitral repair is highly likely, otherwise Class IIa*

The surgical management of acute ischemic mitral regurgitation with papillary muscle rupture is predominantly MVR. In chronic ischemic mitral regurgitation, it is extremely difficult to precisely determine the mechanism of mitral regurgitation preoperatively or intraoperatively. Mitral valve surgery is indicated with 2 to 4+ mitral regurgitation in stable or unstable angina with accompanying revascularization. Mitral regurgitation 2+ is supported by class IIa evidence and 3 to 4 by class I evidence for surgical management. The operation can be tight reduction annuloplasty or replacement, with the surgeon making this decision. Simple annuloplasty may be inadequate — it appears to be effective in the operating room but recurrent mitral regurgitation of moderate intensity may develop months later. The surgical management of chronic, dilated ischemic cardiomyopathy with 2 to 4+ mitral regurgitation requires the same management. The surgical management of chronic, dilated ischemic cardiomyopathy with 3 to 4+ mitral regurgitation and presence of dyskinetic or akinetic scars require the same management plus reduction of ventricular volume and restoration of shape with realignment of papillary muscles. When MVR is performed, subvalvular chordal preservation is always recommended.

Class I recommendations for mitral valve surgery in ischemic mitral regurgitation are listed in Table 6.

Mechanical prosthesis is the choice for MVR unless patients are elderly or have comorbid disease that would justify choice of bioprostheses. Chordal preservation of the posterior leaflet and preferably also the anterior leaflet are recommended for MVR. Mitral valve reconstruction is recommended for degenerative disease in most cases. There are no specific recommendations for the type of annuloplasty ring to be used.

Section V: Tricuspid valve disease in the adolescent and adult

Tricuspid valve dysfunction can occur in patients with structurally normal valves or secondary to organic disease. Organic lesions cause regurgitation, stenosis or more often a combination of both. The majority of patients with triscuspid regurgitation have pulmonary hypertension due to organic or functional left heart disease (eg, mitral stenosis). Triscuspid regurgitation also occurs with RV outflow obstruction or dilated cardiomyopathy. Ebstein's anomaly is the most common congenital abnormality of the tricuspid valve.

Tricuspid repair or replacement is indicated in symptomatic patients not responding to medical therapy or in patients requiring mitral valve surgery, particularly in the presence of pulmonary hypertension or RV dilation and dysfunction. Tricuspid repair is performed for moderate functional triscuspid regurgitation secondary to mitral stenosis at the time of mitral valve surgery.

TABLE 7
Class I recommendations for surgical correction of triscuspid regurgitation

- Tricuspid repair or replacement for severe primary or secondary triscuspid regurgitation, in symptomatic patients not responding to medical treatment; or
- Tricuspid repair or replacement for severe triscuspid regurgitation in patients requiring mitral valve surgery, particularly in the presence of pulmonary hypertension (mean PAP greater than 50 mmHg) or RV dilation and dysfunction.

TABLE 6
Class 1 recommendations for mitral valve (MV) surgery in ischemic mitral regurgitation (MR)

Condition	Recommendation
Acute, post-myocardial infarction MR with cardiogenic shock	
Complete papillary muscle rupture	MV replacement with subvalvar preservation
Partial papillary muscle rupture	MV repair or MV replacement with subvalvar preservation*
Unstable angina with persistent 3+ or 4+ MR	Revascularization plus MV repair (tight annuloplasty ring) or MV replacement with subvalvular preservation
Unstable angina with intermittent 3+ or 4+ MR	
TTE evaluation while ischemia-free	
Persistent 3+ or 4+ MR	Revascularization plus MV repair (tight annuloplasty ring) or MV replacement with subvalvular preservation
Stable angina with 3+ or 4+ MR	
TTE evaluation while ischemia-free	
Persistent 3+ or 4+ MR	Revascularization plus MV repair (tight annuloplasty ring) or MV replacement with subvalvular preservation
Chronic, dilated ischemic cardiomyopathy with 3+ or 4+ MR	Revascularization plus MV repair or MV cardiomyopathy with replacement with subvalvular preservation
Chronic, dilated ischemic cardiomyopathy with 3+ or 4+ MR and presence of akinetic or dyskinetic scar	Revascularization plus MV repair with reduction of annular orifice size or MV replacement with subvalvular preservation* plus obliteration of scar with reduction of LV cavity volume and restoration of shape by ventricular endocardial patch remodelling and realignment of papillary muscles

**Controversy exists between MV repair versus replacement in this population. LV Left ventricular; TTE Transthoracic echocardiography*

Surgery for Ebstein's anomaly is indicated for deteriorating exercise capacity, progressive cyanosis, severe triscuspid regurgitation and paradoxical embolism. Atrial arrhythmia is also considered an indication. Surgery can also be conducted for mild symptoms when repair is likely to be required.

The surgical repair of Ebstein's anomaly includes correction of triscuspid regurgitation and control of intracardiac shunts. The tricuspid valve can be repaired if the anterior leaflet can be mobilized and if it is not obstructing the RV outflow. Plication of the atrialized portion of the RV remains controversial. A more aggressive surgical approach should be considered before the onset of atrial arrhythmia in the presence of the intracardiac shunt to prevent systemic embolization.

TABLE 8
Class I recommendations for surgery in the adolescent or adult with Ebstein s anomaly

- Deteriorating exercise capacity;
- Progressive cyanosis with arterial saturation less than 90% at rest;
- Severe triscuspid regurgitation with increase in symptoms (NYHA functional class III or IV) with or without progressive cardiac enlargement with a cardiothoracic ratio greater than 60%; or
- Paradoxical embolism.

The best type of prosthesis for tricuspid replacement is probably the bioprosthesis because of the low risk of valve thrombosis and infrequent embolic episodes without anticoagulation. The durability of bioprostheses appear better in the tricuspid than the mitral position.

Section VI: Congenital valve disease

Consensus in congenital valve surgery is difficult to achieve because there are some diseases that do not only affect the valves but also other cardiac structures. Pressure overload, volume overload, cyanosis and pulmonary hypertension are all compensated differently in pediatric congenital disease compared with that of the adult. Congenital anomalies are more common in developed countries because pediatric care is better and readily available. Rheumatic disease is still evident in developing countries.

Aortic stenosis: The treatment of critical neonatal aortic stenosis has progressed in the last 20 years. Surgery is not the only alternative. Balloon dilation is accepted as the procedure of choice in centres with an interventional cardiologist. Surgical management is still the first choice in more conservative centres. The pulmonary autograft is the option of choice for replacement in critical aortic stenosis, even in the neonatal period. The problem of RV outflow tract reconstruction remains a challenge but is thought to be a lesser problem than aortic stenosis. The spectrum of hypoplastic left heart syndrome overlaps with critical neonatal aortic stenosis.

Surgical intervention can be postponed in noncritical neonatal and pediatric stenosis because balloon valvotomy can be quite effective for some time. If early surgery is necessary, attempts should be made to preserve the aortic valve at the initial procedure. Surgery with pulmonary autograft replacement of the aortic valve that will preserve LV function has now been established. It is important to remember that surgery in valve diseases is palliative, not curative. These patients, especially the younger ones, will need more surgery in the future and physicians have to be prepared to offer it at the lowest risk possible.

TABLE 9
Class I recommendations for surgical intervention for aortic stenosis in neonates

- Ductal dependent critical aortic stenosis;
- Signs of congestive heart failure (dyspnea, tachycardia, tachypnea, low output);
- Dilated and poorly contractile left ventricle; or
- New-onset ischemic or repolarization changes on electrocardiogram at rest or with exercise (ST depression, T-wave inversion over left precordium) with a gradient greater than 50 mmHg.

TABLE 10
Class I recommendations for aortic balloon valvotomy in infants, children and adolescents

- Symptoms of angina, syncope and dyspnea on exertion, with catheterization peak gradient of 50 mmHg or higher*;
- Catheterization peak gradient greater than 70 mmHg; or
- New-onset ischemic or repolarization changes on electrocardiogram at rest or with exercise (ST depression, T-wave inversion over left precordium) with a gradient greater than 50 mmHg.*

**If gradient is less than 50 mmHg, other causes of symptoms should be explored*

Aortic regurgitation: Aortic regurgitation is often acquired, either iatrogenically (surgery, balloon valvotomy) or naturally from endocarditis, rheumatic fever or associated with congenital defects such as ventricular septal defect. It is a challenge in congenital valvular surgery because proper guidelines are still in development.

TABLE 11
Class I recommendations for aortic valve surgery in children and adolescents with chronic aortic regurgitation

- Onset of symptoms;
- Asymptomatic patients with LV dysfunction (ejection fraction less than 0.55) on serial studies one to three months apart; or
- Asymptomatic patients with progressive LV enlargement (end-diastolic dimension greater than four SD above normal).

Mitral valve disease: Mitral valve disease is still a challenge in pediatric cardiac surgery. Mitral stenosis, although rare, is one of the most complex problems. The small annulus and distorted subannular apparatus make surgery suboptimal. Mitral regurgitation is somewhat easier, but it is still a formidable challenge. Research to achieve a better understanding of the pathophysiology is needed to improve the treatment of these complex lesions.

TABLE 12
Class I recommendations for mitral valve surgery in children with congenital mitral stenosis

- intractable symptoms NYHA class III or IV (small children) despite maximal medical treatment;
- severe growth failure despite maximal medical treatment; or
- symptomatic NYHA class III to IV (older children).

TABLE 13
Class I recommendations for mitral valve surgery in adolescents or young adults with congenital mitral stenosis

- Symptomatic patients (NYHA functional class III or IV) and mean mitral valve gradient greater than 10 mmHg on Doppler echocardiography.

TABLE 14
Class I recommendations for surgery in children with congenital mitral regurgitation

- NYHA functional class III or IV symptoms;
- Congestive heart failure despite maximal medical therapy; or
- LV systolic dysfunction (ejection fraction less than or equal to 0.60; LV systolic volume greater than 60 mL/m^2).

TABLE 15
Class I recommendations for mitral valve surgery in adolescents or young adults with congenital mitral regurgitation

- NYHA functional class III or IV symptoms; or
- Asymptomatic patients with LV systolic dysfunction (ejection fraction 0.60 or lower).

Pulmonary valve disease: Pulmonary stenosis is almost always congenital and is usually treated by balloon valvotomy. It is a rare surgical disease. Severe degenerative disease or stenosis associated with other congenital lesions might require surgical relief but they are now quite rare.

TABLE 16
Class I recommendations for intervention in children with pulmonary stenosis are as follows

- Symptomatic infants with critical pulmonary stenosis;
- Patients with NYHA III to IV (exertional dyspnea, angina, syncope or presyncope) and critical pulmonary stenosis; or
- Asymptomatic patients with normal cardiac output, estimated by echocardiography or by catheterization (RV to pulmonary artery [RV-PA] gradient greater than 50 mmHg).

TABLE 17
Class I recommendations for intervention in adolescents or young adults with pulmonary stenosis

- Patients with exertional dyspnea, syncope or presyncope; or
- Asymptomatic patients with normal cardiac output, by echocardiography or determined by catheterization (RV-PA peak gradient greater than 50 mmHg).

Pulmonary regurgitation is an acquired disease and is best treated with valve replacement. Indications for valve replacement are still to be defined. Ventricular tachycardia, new onset triscuspid regurgitation and RV dilation are accepted as indicated for surgery but early versus late intervention is still in debate.

TABLE 18
Class I recommendations for pulmonary valve replacement in chronic severe pulmonary regurgitation

- Ventricular tachycardia with moderate to severe pulmonary regurgitation.

Tricuspid valve disease: Tricuspid stenosis is often the result of surgery for triscuspid regurgitation; acquired triscuspid regurgitation is secondary to associated pathology. Ebstein disease is one of the most challenging problems in congenital surgery. It can be symptomatic at birth or discovered in adulthood. Its treatment can be as radical as changing from a two ventricle to a single ventricle physiology or as simple as changing the valve.

TABLE 19
Class I recommendations for surgery in neonates and pediatric patients with Ebstein s anomaly and severe triscuspid regurgitation

- Unstable cyanotic newborn with congestive heart failure, in need of mechanical ventilation, prostaglandin dependent and who has failed medical therapy;
- Congestive heart failure;
- Deteriorating exercise capacity (NYHA functional class III or IV); or
- Progressive cyanosis with arterial saturation less than 80% at rest or with exercise.

TABLE 20
Class I recommendations for surgery in adolescents or young adults with Ebstein s anomaly and severe triscuspid regurgitation

- Congestive heart failure;
- Deteriorating exercise capacity (NYHA functional class III or IV); or
- Progressive cyanosis with arterial saturation less than 80% at rest or with exercise.

Valve substitute: Valve replacement can be troublesome in the adult, but in children growth is the issue. The pulmonary autograft is a partial answer to AVR; it has growth potential but the RV outflow tract reconstruction becomes an issue. Mechanical prostheses and anticoagulation, especially in the very young, can be disastrous. Pulmonary valve regurgitation can be treated with either heterograft or homograft insertion but these will have to be replaced. Research has to be focused on a replacement that will last a lifetime. Tricuspid valve replacement is difficult in children; tissue engineering might bring an answer in the future.

Section VII: Valvular disease in the elderly

The primary purpose of valvular surgery in the elderly is to improve quality of life and not necessarily to improve survival except in aortic stenosis. The potential for surgical management for valvular disease in the elderly (ie, over 75 years) differs by valve position and valve lesion.

AVR must be considered in elderly patients who have symptomatic aortic stenosis. Elderly patients with severe aortic stenosis and absence of ventricular dysfunction and CAD can expect a good outcome. The predictors of surgical survival are concomitant CAD, and renal and pulmonary disease.

The elderly patient with aortic regurgitation does less well than aortic stenosis after AVR especially if ventricular dysfunction and congestive heart failure are persistent after surgery.

Symptomatic mitral stenosis is now more common in the elderly because of the changing natural history of rheumatic fever. Balloon valvotomy should be considered in patients who have an increased risk from surgery. Idiopathic calcification of the annulus is a common entity in the elderly. Elderly patients do poorly with surgery for mitral regurgitation; concomitant coronary artery bypass contributes to these poorer outcomes.

Section VIII: Valvular disease in pregnancy

Pregnant women with valvular heart disease remain at risk for cardiac morbid events such as congestive heart failure or arrhythmias. Maternal death during pregnancy in women with heart disease is rare except in those with Eisenmenger's syndrome or pulmonary vascular obstructive disease.

Risk stratification and counselling of women with valvular heart disease is best accomplished before conception. The high risk patients are those with severe symptomatology, significant pulmonary hypertension, Marfan's syndrome with aortic root or valvular involvement, or severe aortic stenosis. The predictors of maternal complications, namely, left heart obstruction, systemic ventricular systolic dysfunction, NYHA greater than II or cyanosis, or history of congestive heart failure, arrhythmia, stroke or transient ischemic attack, have been identified and validated in prospective multicentre studies.

Obstructive valvular lesions are most affected by the hemodynamic changes of pregnancy. Mitral stenosis is the most common valvular lesion encountered during pregnancy.

The recognition and correction of cardiac anomalies should be conducted before a planned pregnancy. Balloon valvotomy or closed cardiac surgery for mitral stenosis should be performed during the first trimester if urgent intervention is necessary.

Cardiopulmonary bypass (CPB) is poorly tolerated during pregnancy with fetal mortality of 10% to 20%. CPB with high flows, high perfusion pressures and normothermia can minimize fetal risk. The optimal timing of surgery is greater than 28 weeks gestation with cesarean section and cardiac correction on CPB.

The optimal type of prosthesis, biological or mechanical, for women considering future childbearing has not been fully defined. Autografts and heterografts can be used for AVR and heterografts for MVR if reconstruction is not feasible. Certainly, biological prostheses should be used for women of childbearing age who would not require anticoagulation for other indications. Pregnancy should be planned during the anticipated durability of the bioprosthesis because reoperation is inevitable. Reoperation should be conducted with mortality of no more than 3% to 4%.

Section IX: Reoperative valvular surgery

The indications for reoperative valvular surgery are PVE, prosthesis thrombosis, paravalvular leak or prosthesis dehiscence, bioprosthetic structural failure, pannus formation, prophylactic prosthesis rereplacement, and prosthesis replacement in conjunction with other cardiac procedures.

The diagnostic assessment, surgical approaches and procedural considerations are detailed as the principles and techniques to optimize safety and maintain low operative mortality for reoperative valvular surgery.

Section X: Pathology of prosthetic heart valves

The pathology of prosthetic heart valves is presented to familiarize cardiologists, internists, family physicians and cardiac surgeons to the potential early postoperative failure and late complications that can contribute to mortality related to cardiac valvular prostheses. The specific complications of mechanical prosthetic valves and bioprostheses that can contribute to urgent and emergent clinical situations are presented for the optimization of immediate (if indicated) and appropriate management. The pathological features of valve-related complications, namely, paravalvular leaks, thrombosis, thromboemboli, infective endocarditis, tissue degeneration and dysfunction, and host tissue overgrowth are detailed for mechanical and biological prostheses. The specific materials degeneration of both mechanical prostheses and bioprostheses that can influence the clinical status of patients is also detailed. The section provides a proposed protocol for evaluation of explanted devices.

Section XI: Echocardiographic guidelines

The section on echocardiographic guidelines details the evaluation methodology to provide the most complete and specific information with regard to the nature and severity of valvular disease. The information provided by the echocardiographic examination will influence the type of operation to be performed in a particular situation, specifically with regard to reconstruction or replacement for chronic mitral regurgitation.

The echocardiographic standards have been developed for the reporting of acute and chronic mitral regurgitation to facilitate the planning and execution of mitral valve reconstructive surgery.

The responsibility roles of the echocardiologist and anesthesiologist in the operating room have been considered and are presented for implementation. The training requirements for cardiologists and anesthesiologists are presented as a proposal for the cardiovascular community.

The echocardiographic guidelines also provide recommendations for surveillance of valve reconstruction and valve replacement, as well as autograft aortic root reconstruction and pulmonary root replacement. The echocardiography working group was committed to the development of consensus for echocardiographic guidelines for Canadian centres.

Section XII: Advances in prosthetic valve design and function

The current status of mechanical prosthetic and bioprosthetic technology is summarized in this section. The engineering strategies that are under development to reduce the complications of degeneration of bioprostheses and thromboembolism with mechanical prostheses are presented as a glimpse into the future of prosthetic designs and material preservation.

Section XIII: Antithrombotic therapy for prosthetic heart valves

The current opinion on antithrombotic therapy for prosthetic heart valves is summarized. The recommendations for antithrombotic therapy are presented by consensus in Tables 23 and 24.

Section XIV: Native and PVE

The recommendations for surgery for native valve endocarditis (NVE) and PVE are presented and the consensus status indicated. The section details the cardiac conditions that are associated with endocarditis. The recommended prophylactic regimens for dental procedures and oral, respiratory tract, esophageal and gastrointestinal procedures are presented in tabular form.

TABLE 21
Class I recommendations for surgery for NVE

- Aortic regurgitation or mitral regurgitation with heart failure;
- Acute aortic regurgitation with tachycardia and early closure of the mitral valve;
- Fungal endocarditis;
- Evidence of annular or aortic abscess, sinus or aortic true or false aneurysm;
- Evidence of valve dysfunction and persistent infection after a prolonged period (seven to 10 days) of appropriate antibiotic therapy, as indicated by presence of fever, leukocytosis and bacteremia, provided there are no noncardiac causes for infection.

TABLE 22
Class I recommendations for surgery for PVE

- Early PVE (first two months or less after surgery);
- Heart failure with prosthetic valve dysfunction;
- Fungal endocarditis;
- Staphylococcal endocarditis not responding to antibiotic therapy;
- Evidence of paravalvular leak, annular or aortic abscess, sinus or aortic true or false aneurysm, fistula formation or new-onset conduction disturbances; or
- Infection with Gram-negative organisms or organisms with a poor response to antibiotics.

Section XV: Specific definitions and guidelines
These include the following:

- definitions of NYHA classification of congestive heart failure;
- definitions of CCS grading of angina;
- guidelines for reporting morbidity and mortality after cardiac valve operations;
- proposal for clinical valve surgery database;
- proposed protocol for evaluation of explanted prosthetic heart valve devices;
- Duke criteria for clinical diagnosis of definite infective endocarditis;
- cardiac conditions associated with endocarditis; and
- prophylactic regimens for endocarditis prevention.

SECTION II: RESEARCH ISSUES AND KNOWLEDGE GAPS TO IMPROVE QUALITY OF EVIDENCE

The extensive literature on valve replacement and reconstructive surgery has not been derived from randomized studies. The evidence base for indications for surgery and the specifics of surgical management are based on general agreement from retrospective and prospective evaluations. There remain areas where there is divergence of opinion or conflicting evidence. The historical retrospective and comparative studies are often flawed by involuntary bias. These areas can be identified as knowledge gaps and, thus, create issues for research endeavours.

TABLE 23
Recommendations for antithrombotic therapy: Indications for mechanical prosthetic valves

Type of valve	Recommendation
Mechanical (all oral anticoagulants)	Unfractionated heparin or low molecular weight heparin until INR therapeutic 2 days
Aortic valve replacement	
Bileaflet St Jude Medical*	Warfarin, INR 2.0 to 3.0
Bileaflet Carbomedics*	Warfarin, INR 2.0 to 3.0
Tilting disc Medtronic Hall*	Warfarin, INR 2.0 to 3.0
Bileaflet	Warfarin, INR 2.5 to 3.5
Bileaflet ( )	Warfarin, INR 2.0 to 3.0 plus ASA, 80 to 100 mg/day
Mitral valve replacement	
Bileaflet and tilting disc	Warfarin, INR 2.5 to 3.5
Bileaflet and tilting disc ( )	Warfarin, INR 2.0 to 3.0 plus ASA, 80 to 100 mg/day
Mechanical (aortic-mitral)§	Warfarin, INR 2.5 to 3.5 plus ASA, 80 to 100 mg/day
Mechanical (aortic-mitral)¶	Warfarin, INR 2.5 to 3.5 plus ASA, 80 to 100 mg/day

**Sinus rhythm and left atrium normal size; Atrial fibrillation; Alternative recommendation; §Risk factors: atrial fibrillation, left ventricular dysfunction, previous thromboembolism and hypercoagulable conditions; ¶Systemic embolism. ASA Acetylsalicylic acid; INR International normalization ratio*

TABLE 24
Recommendations for antithrombotic therapy: Indications for bioprosthetic valves

Type of valve	Recommendation
For three months following valve replacement	
Aortic	Acetylsalicylic acid/warfarin
Mitral	Warfarin
	Heparin (low molecular weight or unfractionated) until INR therapeutic 2 days
For three months following valve replacement	
Aortic or mitral	Warfarin INR 2.0 to 3.0
Three months or more following valve replacement	
Aortic or mitral*	Warfarin INR 2.0 to 3.0
Aortic or mitral	Warfarin INR 2.0 to 3.0
Aortic or mitral	Warfarin INR 2.5 to 3.0 for 3 to 12 months
Aortic or mitral§	Acetylsalicylic acid 80 mg/day

**Atrial fibrillation; Left atrial thrombus at surgery; History of systemic embolism; §Sinus rhythm. INR International normalizaton ratio*

The creation of a national data bank with simple and concise data would be a formidable tool. The data bank should store essential data and facilitate long term follow-up with ease of data retrieval. A permanent committee of surgeons and cardiologists with interest in valvular disease should be established to supervise the data bank and its use. The National Valve Data Bank should become an integral part of a future potential Canadian Cardiovascular Information Network.

The establishment of a National Valve Data Bank is certainly consistent with the current atmosphere in the international cardiovascular community. The Society of Thoracic Surgeons (STS) administers the National Cardiac Surgery Database which provides risk stratified early clinical results for Canada and its other participating centres. Several Canadian centres currently submit data to the STS database on an annual basis.

The STS is now formulating a longitudinal outcomes data set which has been developed with significant Canadian input. The European Association of Cardio-Thoracic Surgery is currently promoting an international cardiac surgery database system involving Europe, North America, Asia, Australia and New Zealand.

The goals of a National Valve Data Bank in Canada would support comparative studies of prosthesis performance, evaluation of new technology and extension of management indications in groups characterized by clinical symptomatology and parameters of ventricular function; this would be available in all groups of patients from the neonate to the elderly.

The recommendations to facilitate research in the surgical management of valvular heart disease are as follows:

A. General

1. Develop a National Valve Data Bank as an integral part of a future Canadian Cardiovascular Information Network using the Society of Thoracic Surgery Cardiac Database operative module and the proposed longitudinal outcomes module;
2. Give consideration to implementation of recommendations for surveillance of valve reconstruction, valve replacement, autograft aortic root reconstruction and pulmonary root replacement to optimize patient care, monitor functional recovery and identify any progression over time of ventricular and prosthesis reconstruction dysfunction;
3. Develop a comprehensive National Collaborative Evaluation of new prosthetic devices;
4. Support the advancement of regulatory guidelines for sizing terminology and standards for both mechanical prostheses and stented and stentless bioprostheses;
5. Consider the development of an objective, functional classification of performance as an alternative to the subjective NYHA functional classification;
6. Develop a system of documentation of performance and technical considerations of complex operative procedures;
7. Perform regulatory investigative studies in designated centres committed to evaluating endeavors to facilitate short evaluation intervals and provide the opportunity for randomization to established prostheses (this evaluation method would replace comparison to historical studies);
8. Designate new surgical techniques that should be performed under protocol with a clear description of techniques so that multicentre evaluation can be conducted (proper surgical techniques are paramount in the conduct of new surgical procedures);
9. Clarify the evidence-based classification of IIa and IIb various valvular lesions;
10. Evaluate the management of the dilated and aneurysmal aorta with prospective data;
11. Clarify the extremes of LV hypertrophy and ventricular dilation and their influence on survival;
12. Establish a protocol for assessment of the management of prosthesis thrombosis;
13. Evaluate the influence of second and third generation bioprostheses;
14. Assess ventricular restoration surgery and mitral reconstruction and replacement in the management of ischemic dilated cardiomyopathy;
15. Evaluate the optimal timing of surgical management of native and PVE;
16. Evaluate the surveillance protocols for optimizing reoperative surgery for bioprosthetic structural valve degeneration;
17. Evaluate electron beam tomography for aortic wall and cusp calcification in homograft and stentless bioprosthetic root replacement;
18. Assess performance of bioprostheses and mechanical prostheses in chronic dialysis dependent renal failure.

B. Aortic valve disease

1. Develop a specific Central Registry of Results of Pulmonary Autograft AVR (contribute to the role of this advancing complex procedure);
2. Develop a multicentre evaluation of the concept of prosthesis-patient mismatch with various prostheses by operative measurement of annular diameter with graduated sizers and indexing to body surface area based on reference EOAs (opportunity to optimize hemodynamics and evaluate influence on short and long term patient survival);
3. Evaluate asymptomatic severe aortic stenosis considering such echocardiographic parameters as LV hypertrophy and velocity across the LV outflow tract (LVOT);
4. Evaluate AVR in symptomatic severe noncritical aortic stenosis with low transvalvular gradients and LV dysfunction;
5. Document the role of exercise testing in asymptomatic aortic stenosis as an investigative modality;
6. Evaluate the role of AVR with myocardial revascularization;
7. Assess the management of symptomatic chronic aortic regurgitation with advanced LV dysfunction;
8. Assess the role of AVR at the time of coronary artery bypass in patients with mild to moderate aortic stenosis;
9. Determine the pathological relationship between bicuspid aortic valve and aortic wall structure;
10. Evaluate the role of natriuretic peptide levels in the timing of AVR for severe chronic aortic regurgitation;
11. Determine survival predictors in severe aortic stenosis;
12. Assess pulmonary autograft dilation in the systemic circulation;
13. Participate in research in tissue engineering for valvular prostheses;

14. Participate in studies of contribution of atheromatous changes to the pathogenesis of native aortic stenosis and bioprosthetic degeneration;
15. Evaluate aortic valve-sparing procedures, specifically reimplantation and remodelling;
16. Assess factors influencing LV hypertrophy regression in the management of aortic stenosis;
17. Evaluate association between bicuspid aortic valve disease and pulmonary valve defects (influences on use of pulmonary autografts);
18. Assess the significance of mitral regurgitation concomitant with AVR for aortic stenosis;
19. Determine the role of AVR for asymptomatic moderate to severe aortic stenosis for noncardiac surgery;
20. Evaluate whether the concept of 'wait for events' is generally safe for patients with aortic stenosis.

C. Mitral or tricuspid valve disease

1. Further evaluate the management of patients with severe nonischemic mitral regurgitation with severe LV dilation and systolic dysfunction (proposal for multicentre consideration);
2. Further consideration of the management of ischemic mitral regurgitation regarding indications and outcomes of annuloplasty and valve replacement with chordal sparing;
3. Assess the role of surgical ventricular reconstruction and mitral regurgitation management in chronic dilated ischemic cardiomyopathy with severe mitral regurgitation;
4. Determine the role of atrial fibrillation ablation surgery as a concomitant procedure to mitral valve surgery;
5. Assess tricuspid valve replacement in carcinoid heart disease (role of bioprostheses);
6. Assess devices to control ventricular remodelling in ischemic cardiomyopathy;
7. Determine the survival benefit of surgical timing of mitral valve reconstruction or replacement in nonischemic mitral valve regurgitation (moderate and severe);
8. Determine the influence of age in management of symptomatic and asymptomatic nonischemic mitral regurgitation;
9. Assess mitral homografts for replacement of the tricuspid valve.

D. Congenital valve disease

1. The National Valve Data Bank should incorporate the Canadian experience in congenital heart valve surgery as a major contribution to consensus development;
2. Clarify the evidence-based classification of IIa and IIb in the various valvular lesions;
3. Evaluate the potential for earlier surgical intervention for Ebstein's anomaly;
4. Develop guidelines for the management of aortic regurgitation;
5. Improve the understanding of the pathophysiology of mitral stenosis and mitral regurgitation.

E. Valvular disease in pregnancy

1. Develop a risk stratification protocol for the management of valvular disease in women of childbearing age and during pregnancy as a potential Canadian project;
2. Perform clinical trials of optimal anticoagulation strategy for mechanical valve patients during pregnancy.

F. Pathology of prosthetic heart valves

1. Develop a National Pathology Registry of explanted prostheses to facilitate advances in prosthesis development and reduce dependency on reporting from industry.

G. Echocardiographic

1. Develop a frame of reference to advance echocardiographic standards and the provision of greater uniformity between echocardiography laboratories in Canada;
2. Develop standards for echocardiography reporting of mitral regurgitation, specifically related to degenerative disease, to facilitate optimal planning and conduct of mitral valve reconstructive procedures;
3. Develop responsibility roles for the echocardiologist and anesthesiologist in the operating room with associated recommended training requirements;
4. Develop evaluation methods for new echocardiographic assessment modalities at a multicentre level for purposes of validation for standard clinical application;
5. Develop more accurate methods to predict irreversible LV dysfunction in patients with regurgitant lesions to assist in determining the timing of surgical intervention (ie, tissue Doppler, total ejection isovolume index);
6. Assess methods to determine correct timing of surgical intervention in patients with multiple regurgitant lesions (ie, mitral regurgitation and aortic regurgitation);
7. Assess methods to select correct therapy for patients with LV dysfunction and 'secondary' or functional mitral regurgitation (can subgroups be differentiated for benefit for mitral valve repair or replacement?);
8. Determine the natural history of mild and moderate mitral regurgitation and the determinants of progression to severe mitral regurgitation;
9. Determine more precise indications for surgery in patients with low flow or low gradient aortic stenosis;
10. Develop a more refined interpretation of dobutamine stress echocardiography in low flow or low gradient aortic stenosis;
11. Develop a more refined quantification of regurgitant fraction in mitral regurgitation.

H. Antithrombotic therapy

1. Support national and provincial programs of patient-controlled home anticoagulation for mechanical prostheses to optimize care and minimize valve-related complications of thromboembolism and bleeding events;

2. Establish a protocol for the assessment and management of prosthesis thrombosis (thrombolysis and surgery);
3. Improve anticoagulant programs to reduce the risk of thromboembolism and bleeding;
4. Assess self-controlled anticoagulation (study of complications in the elderly);
5. Determine thromboembolism risk scoring as a guide to antithrombotic management.

SECTION III: AORTIC VALVE, AORTIC ROOT AND SUBVALVULAR DISEASE

AORTIC STENOSIS

Etiology

The most common causes of aortic stenosis, in order of prevalence, are degenerative calcific, congenital bicuspid and rheumatic disease. Rheumatic aortic valve disease is common worldwide but is infrequent in western countries, and is invariably accompanied with rheumatic mitral valve disease. Calcific aortic valve disease presents with the congenital bicuspid valve at 50 to 60 years of age and with the normal trileaflet valve at 60 to 80 years of age (1-3). Calcific degenerative aortic stenosis may be arteriosclerotic in origin.

Pathophysiology

Valvular obstruction develops gradually, usually over several decades. The ventricle adapts to systolic pressure overload through a myocardial hypertrophic process. Systolic wall stress is minimized by the increase in wall thickness and ejection fraction is preserved. If the hypertrophic process is inadequate, wall stress will increase and the high afterload will cause a decrease in ejection fraction. The major compensatory hypertrophic mechanism will fail by impairment of LV systolic function (ejection fraction) as a result of afterload/preload mismatch. There will be increases in LV end-diastolic pressure and LA pressure, often resulting in pulmonary edema. This increase in end-diastolic pressure usually reflects diastolic dysfunction rather than systolic dysfunction and congestive failure. The concentric hypertrophy of the myocardium results in limited coronary vasodilator reserve and can cause ischemia, arrhythmia and sudden death. Hypertrophy contributes to ventricular fibrosis, and diastolic and systolic dysfunction that are incompletely reversible after surgery. The dysfunction is not purely a result of high afterload.

The normal aortic valve orifice area is 3.0 to 4.0 cm^2, and an area of less than 1.0 cm^2 is considered severe aortic stenosis. Mild aortic stenosis is defined as a valve area greater than 1.5 to 2.0 cm^2, moderate as 1.0 to 1.5 cm^2, and severe as less than 1.0 cm^2. Aortic valve area (AVA) indexed to body surface area should be considered for the large and small extremes of body surface area. Mild aortic stenosis is defined as indexed AVA greater than 0.9 cm^2/m^2, moderate between 0.6 to 0.9 cm^2/m^2, and severe as less than 0.6 cm^2/m^2. With severe stenosis, the mean transvalvular pressure gradient is usually greater than 50 mmHg. Patients with severe aortic stenosis may be asymptomatic, while moderate aortic stenosis can produce symptoms. The hemodynamic effects of aortic stenosis are related to factors other than grade of stenosis, including the systemic blood pressure and LV response (4).

Natural history

There is usually a prolonged latent period with low morbidity and mortality (5-12). Cardiac catheterization and echocardiographic studies show that the decrease in valve area can range from 0.1 to 0.3 cm^2 per year and the mean pressure gradient increase can be as much as 5 to 11 mmHg per year (13-19). The average valve area change is 0.12 cm^2 per year (14,15). The onset of symptoms of angina, syncope and heart failure usually result in an average duration of survival of less than two to three years (20,21). The development of symptoms is a critical point in the natural history of aortic stenosis. Sudden death is known to occur with aortic stenosis but rarely without prior symptoms. In severe aortic stenosis, symptoms appear in 40% to 70% of patients by two years and in 80% by three years (15,22). The mortality by 10 years is 80% to 90% (1).

Diagnosis

Two-dimensional and Doppler echocardiography are extremely important and useful for assessment of aortic stenosis (14,23-25). Aortic valve peak instantaneous pressure gradient, mean pressure gradient and valve area may be determined by Doppler interrogation of the aortic valve (26-29). The calculation of AVA should be performed in conjunction with measurement of the pressure gradient for determining the severity of aortic stenosis. The echocardiographic guidelines are detailed in section XI.

The severity of aortic stenosis is usually graded by Doppler echocardiography or cardiac catheterization as mild, moderate or severe. Transvalvular pressure gradients may be used to grade aortic stenosis severity in patients with normal LV function and cardiac output, in the absence of aortic regurgitation. In general, mean transvalvular pressure gradients greater than 50 mmHg represent severe aortic stenosis, while mean gradients less than 25 mmHg suggest mild aortic stenosis (30).

The normal valve area is 3.0 to 4.0 cm^2. The normal valve area in small people may be less than 3.0 cm^2. In general, severe aortic stenosis has been defined as a valve area of 0.75 to 1.0 cm^2 (32). Mild aortic stenosis has generally been defined as an AVA greater than 1.2 to 1.5 cm^2.

For the purpose of this consensus document, severe aortic stenosis is considered to be an AVA less than 1.0 cm^2 (20,31-33). This is based on the observation that the vast majority of patients with symptomatic aortic stenosis have AVAs less than 1.0 cm^2 and a lower ‘cut-off’ value may lead to a significant number of symptomatic patients being classified as having nonsevere aortic stenosis.

It is important to recognize that the absolute valve area may not be an ideal index of aortic stenosis severity in patients of large or small body size (34). In large patients, valve areas greater than 1.0 cm^2 may represent severe aortic stenosis while valve areas less than or equal to 1.0 cm^2 may be adequate in small patients (35). The indexed AVA classification is listed in Table 25.

In the setting of normal LV function and the absence of a high subvalvular velocity, severe stenosis is determined by a peak velocity greater than 4.0 to 4.5 m/s or mean gradient greater than 50 mmHg at the valve (15,20). The jet velocity of mild stenosis is greater than 2.5 m/s and that of moderate stenosis is 3 to 4 m/s. Aortic regurgitation is present in 80% of patients with aortic stenosis.

Low output/low gradient aortic stenosis is an uncommon but challenging problem where the calculated small AVA does not correspond with the low mean pressure gradient (36-39). Normalization of cardiac output with dobutamine with a resultant mean gradient greater than 30 mmHg is suggestive of severe aortic stenosis while gradients less than 30 mmHg suggest only mild aortic stenosis (39-42). Severe aortic stenosis is likely not present if the AVA increases to greater than 1.0 cm^2 to 1.2 cm^2 with dobutamine infusion. If the cardiac output does not change and the mean pressure gradient is less than 30 mmHg, there is impaired myocardial reserve.

Coronary angiography is recommended in symptomatic patients with aortic valve disease before surgery, because up to 50% of patients may have coexisting CAD. Coronary angiography may not be required in young patients (less than 35 years old) who have no risk factors for CAD. Routine carotid artery assessment is suggested in the preoperative work-up of a patient with aortic stenosis being considered for surgery.

Indications for intervention

AVR is the surgical intervention of choice. Balloon valvotomy may be appropriate for children and adolescents with congenital aortic stenosis, but not in adults with calcific aortic stenosis. Ultrasonic or mechanical debridement procedures have been abandoned (43-44).

Asymptomatic aortic stenosis: There is no consensus for valve replacement in the truly asymptomatic patient (45-53). Because the natural history is unknown in the asymptomatic patient with severe aortic stenosis, it may be reasonable to recommend AVR, but the risk of sudden death without surgery is small (0.4% per year) in asymptomatic patients and is outweighed by the surgical risks of AVR. Although patients usually develop symptoms before death, there may be insufficient time between symptom onset and death to intervene (20,21,46,48). The concept of 'sudden death' should be replaced by 'death before surgery can be accomplished'. This takes the risk to at least 7% and maybe higher (46,48). There is no definite consensus to operate in the absence of symptoms. The exceptions may be LV dysfunction secondary to aortic stenosis or exercise induced hypotension. This dictates the need to conduct exercise testing to be certain that the patient is truly asymptomatic (15,54).

AVR is associated with low perioperative morbidity and mortality, but long term morbidity and mortality with both mechanical prostheses and bioprostheses are appreciable (55-58). The significant complications occur at a rate of 2% to 3% per year for both types of prostheses, and prosthesis-related mortality is approximately 1% per year.

Symptomatic aortic stenosis: AVR increases survival and quality of life for patients with severe aortic stenosis (AVA less than 1.0 cm^2) (20,30,32,59-64). The outcome is similar with normal ventricular function and moderate depression of contractile function. Depressed ejection fraction due to afterload mismatch improves after valve replacement. If LV dysfunction is not due to afterload mismatch, full recovery of dysfunction and complete resolution of symptoms may not be achieved. Symptomatic patients with AVA greater than 1.0 cm^2 should be investigated for other etiologies of their symptoms, unless they have an increased body size and indexed AVA less than 0.6 cm^2/m^2.

TABLE 25
Aortic valve area (AVA) classification

	AVA	Indexed AVA
Mild	>1.5 cm^2	>0.9 cm^2/m^2
Moderate	1.0 to 1.5 cm^2	0.6 to 0.9 cm^2/m^2
Severe	<1.0 cm^2	<0.6 cm^2/m^2

Aortic stenosis combined with severely impaired LV systolic function poses a difficult clinical management problem (20,54,65). If the gradient is low due to moderate stenosis with LV dysfunction caused by primary myocardial disease, the outcome will be marginal with persistence of LV dysfunction and symptoms. Valve replacement should not be recommended in the absence of anatomically severe stenosis. Impairment of LV function with transaortic resistance greater than 225 dynes•s•cm^{-5}, is another guide to severe aortic stenosis which may be better than effective orifice area. Dobutamine stress testing can help with the decision-making. Dobutamine has potentially two functions, namely, determination of severity of stenosis and degree of LV contractile reserve. Even if aortic stenosis is severe, surgery may be inappropriate if there is irreversible LV failure (66,67). If the mean gradient is greater than 40 mmHg, AVR can provide symptomatic improvement with acceptable mortality (65,68,69). The outlook is worse with low output aortic stenosis and low gradient (mean gradient less than 30 mmHg) (39,70). The dobutamine evaluation can help in decision making (40-42,71).

In summary, dobutamine echocardiography usually reveals that only one-third of low gradient aortic stenosis (0.6 to 0.8 cm^2, mean gradient less than 30 mmHg) appear to have noncritical aortic stenosis; one-third has critical aortic stenosis and one-third is indeterminate. The indeterminate group has a poor prognosis with medical therapy and likely should be offered surgery, although their outlook may be poor (Table 26).

CAD and aortic stenosis: Patients with CAD and severe aortic stenosis, with or without symptoms, should have concomitant AVR (72). The same indications should hold for aortic root or mitral valve surgery. It is generally acceptable practice to perform AVR when the mean gradient is 25 mmHg or higher, which corresponds to a peak transaortic velocity of greater than 3.0 m/s. A mean gradient of less than 25 mmHg and peak velocity of greater than 2.0 m/s suggests some degree of fibrocalcific thickening of the aortic valve cusps but only mild aortic stenosis. This is generally not an indication for surgery except in the setting of severely depressed LV systolic function, where further evaluation including AVA calculation and dobutamine stress echocardiography may be needed to clarify aortic stenosis severity (73). Moderate aortic stenosis may warrant AVR in selected cases such as when the patient is symptomatic or is undergoing coronary artery bypass graft (CABG) surgery (72).

Patients with severe aortic stenosis undergoing CABG should have concomitant AVR (74-81). The majority of asymptomatic patients with severe aortic stenosis will progress to symptoms within three years and the risk of prophylactic AVR with CABG is smaller than the risks of AVR following coronary artery bypass surgery (82,83). Patients with asymptomatic moderate aortic stenosis also have a high rate of progression to symptoms within three years and may also benefit from

TABLE 26
Recommendations for aortic valve replacement in aortic stenosis (AS)

Indication	Class	
1. Symptomatic patients with severe AS	I	B
2. Patients with severe AS undergoing coronary artery bypass surgery	I	B
3. Patients with severe AS undergoing surgery on the aorta or other heart valves	I	B
4. Patients with moderate AS undergoing coronary artery bypass surgery or surgery on the aorta or other heart valves	IIa	C
5. Asymptomatic patients with severe AS and:		
Left ventricular systolic dysfunction	IIa	C
Abnormal response to exercise (eg, hypotension)	IIa	C
Ventricular tachycardia	IIb	C
6. Patients with mild AS undergoing coronary artery bypass surgery	IIb	C
Contraindication	**Class**	
7. Asymptomatic patients with severe AS and:		
Marked or excessive left ventricular hypertrophy (≥15 mm)	III	C
Valve area <0.6 cm^2	III	C
8. Prevention of sudden death in asymptomatic patients with none of the findings listed under indication 7	III	C

Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29)

prophylactic AVR (20). The decision for prophylactic AVR in patients with mild aortic stenosis is controversial (84,85). The natural history of mild aortic stenosis is variable with some patients progressing to more severe stenosis while others remain stable (86). The decision to perform prophylactic AVR will subject a significant number of patients to the morbidity and mortality of a combined procedure and long term risks of a prosthesis, which may never have been necessary. A retrospective comparison of patients requiring AVR subsequent to coronary artery bypass surgery and patients receiving simultaneous AVR and coronary artery bypass surgery demonstrated no difference in 10-year survival. Further, a retrospective review of patients with mild aortic stenosis who underwent isolated coronary artery bypass surgery or coronary artery bypass surgery and concomitant AVR demonstrated no difference in event-free survival with the latter procedure (87,88). However, patients with calcified valves and larger transvalvular pressure gradients may be at increased risk of progression to more severe aortic stenosis (Table 27).

Aortic balloon valvotomy: The procedure may be considered a 'bridge' to surgery if severe aortic stenosis is complicated by refractory pulmonary edema or cardiogenic shock. The most acceptable bridge to surgery for pulmonary edema or cardiogenic shock is treatment with inotropes and vasoconstrictors. Aortic balloon valvotomy provides only a moderate reduction of transvalvular gradient, and postvalvotomy area rarely exceeds 1.0 cm^2. The procedure complication rate is greater than 10% and is not a substitute for AVR (Table 28).

The operative mortality for patients less than 70 years of age with isolated AVR is 3% to 5%. The risk factors of mortality are age, female sex, emergency surgery, coexisting CAD, hypertension, LV dysfunction, renal failure and concomitant mitral valve surgery.

AORTIC REGURGITATION

Etiology

The most common causes of aortic regurgitation are idiopathic dilation, congenital anomalies of the aortic valve (mostly bicuspid valves), rheumatic disease, calcific degeneration, myxomatous degeneration, systemic hypertension, infective endocarditis, Marfan's syndrome and dissection of the ascending aorta. The less common causes are ankylosing spondylitis, traumatic injury and ventricular septal defect with prolapsing cusp. The majority of the lesions produce chronic aortic regurgitation. Aortic dissection, infective endocarditis and trauma produce acute severe regurgitation.

Pathophysiology

Acute aortic regurgitation: The left ventricle cannot tolerate a sudden large volume overload. The abrupt increase in end-diastolic volume causes LV end-diastolic and LA pressures to rise rapidly and excessively. The ventricle cannot develop compensatory chamber dilation and forward stroke volume is consequently decreased. The clinical presentation is usually that of pulmonary edema or cardiogenic shock. Patients who have pressure overload hypertrophy from systemic hypertension or pre-existing aortic stenosis, develop an even more acute clinical condition because of the reduced preload reserve and high diastolic pressure-volume relationship. The compensatory tachycardia in these situations is unable to maintain cardiac output.

Chronic aortic regurgitation: The left ventricle in chronic aortic regurgitation compensates for the severe volume load by a number of mechanisms, including an increase in LV end-diastolic volume, an increase in chamber compliance to accommodate increased volume without increase in diastolic filling pressures, and through eccentric hypertrophy. The increased diastolic LV volume permits a large stroke volume and maintenance of cardiac output (forward stroke volume) in a normal range. The overall LV ejection performance is normal with the ejection fraction remaining normal. While disease progression results in progressive LV chamber dilation, systolic LV function can be maintained for up to several decades through continued preload recruitment and compensatory hypertrophy.

The balance between afterload excess, preload reserve and compensatory hypertrophy cannot be maintained indefinitely. Further increases in afterload can result in reduction in systolic ejection performance and the ejection fraction can decrease below normal at rest (measure of LV systolic dysfunction). Patients become symptomatic at this stage with fatigue, dyspnea and exertional angina. Progressive systolic dysfunction occurs with progressive chamber enlargement and depressed myocardial contractility.

Natural history

The natural history of acute aortic regurgitation is relatively rapid progression to death (5,27,89-98). The natural history of chronic aortic regurgitation is dependent on symptomatic status and LV systolic dysfunction (99).

The asymptomatic patient with normal LV systolic function and chronic regurgitation has not been adequately evaluated with regard to natural history (100,101). Limited clinical evaluations have shown that the rate of progression to symptoms or LV systolic dysfunction averages 4.3% per year (asymptomatic LV dysfunction occurs less than 3.5% per year, and symptoms

TABLE 27
Recommendations for aortic valve replacement in patients undergoing coronary artery bypass surgery

Indication	Class	
1. In patients undergoing CABG who have severe AS who meet the criteria for valve replacement	I	B
2. In patients undergoing CABG who have moderate AS (mean gradient 30 to 50 mmHg or Doppler velocity 3 to 4 m/s)	IIa	C
3. In patients undergoing CABG who have mild AS (mean gradient ≤25 mmHg or Doppler velocity ≤3 m/s)	IIb	C

AS Aortic stenosis; CABG Coronary artery bypass grafting

TABLE 28
Recommendations for aortic balloon valvotomy in adults with aortic stenosis

Indication	Class	
1. A bridge to surgery in hemodynamically unstable patients who are at high risk for aortic valve replacement	IIb	C
2. Palliation in patients with serious comorbid conditions	IIb	C
3. Patients who require urgent noncardiac surgery	IIb	C
Contraindication	**Class**	
4. An alternative to aortic valve replacement	III	C

Recommendations for aortic balloon valvotomy in adolescents and young adults with aortic stenosis are provided in section VI; Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29)

or LV dysfunction occurs less than 6% per year). The incidence of sudden death is less than 0.2% per year. The rate of progression to cardiac symptoms in asymptomatic patients with LV systolic dysfunction is greater than 25% per year. The mortality rate of symptomatic patients is greater than 10% per year with angina pectoris and greater than 20% per year with congestive heart failure.

Diagnosis

Echocardiography allows for the diagnosis and semiquantitation of aortic regurgitation severity, in addition to providing a method for serial assessment of regurgitation severity, LV chamber size and systolic function (102). The etiology of the regurgitation can usually be determined from two-dimensional echocardiography by assessing the valve morphology and aortic root. Accurate assessment of aortic regurgitation severity can be difficult and requires a comprehensive evaluation of several Doppler parameters because no single measure provides an entirely accurate quantitative assessment. The echocardiographic guidelines are detailed in section XI.

The grading of aortic regurgitation using the colour flow Doppler aortic regurgitation jet diameter compared with the LVOT diameter ratio is shown in Table 29. A colour flow Doppler aortic regurgitation jet to LVOT diameter ratio of greater than 65% indicates severe aortic insufficiency and generally correlates with holo-diastolic flow reversal in the descending aorta beyond the arch. An aortic regurgitation jet pressure half-time of 400 msec suggests severe aortic regurgitation and a pressure half-time of 250 msec almost always represents severe aortic regurgitation. An aortic regurgitant volume of greater than 60 mL/beat and a regurgitant fraction of greater than 50% are consistent with severe aortic regurgitation. Newer Doppler approaches to the assessment of aortic regurgitation severity include the vena contracta width (narrowest diameter of the colour flow Doppler aortic regurgitation jet as it emerges through the valve orifice) and the effective aortic regurgitant orifice area. A vena contracta width greater than 7 mm is strongly suggestive of severe aortic regurgitation. As with all other types of valvular pathology, the accurate assessment of aortic regurgitation severity by Doppler echocardiography requires the careful integration of multiple parameters by an experienced echocardiography laboratory.

Coronary angiography is recommended in patients being considered for surgical intervention if they have angina, LV dysfunction, a history of CAD or risk factors for CAD (including age greater than 35 years).

Indications for surgical intervention

AVR is considered only when chronic aortic regurgitation is severe (103,104). AVR should be performed when significant cardiac symptoms develop or there is evidence of progressive LV dilation (105). With improvements in surgical outcome, earlier operation may now be indicated when minimal or no cardiac symptoms accompany evidence of LV systolic dysfunction (106).

The factors predictive of reduced postoperative survival and recovery of LV dysfunction are severity of preoperative symptoms or reduced exercise tolerance, severity of depression of LV ejection fraction, and duration of preoperative LV systolic dysfunction. By the time symptoms develop, some patients may have developed irreversible LV dysfunction and will be at risk of postoperative congestive heart failure and death.

In symptomatic patients, ejection fraction at rest is the most sensitive indicator of outcome following AVR. In asymptomatic patients, the time interval between the development of LV dysfunction at rest and onset of symptoms may be less than two to three years (107). Long term outcome is enhanced in asymptomatic or mildly symptomatic patients with LV dysfunction compared with more symptomatic patients (108-110). As stated, both severity and duration of preoperative LV dysfunction are determinants of survival and reversibility of LV dysfunction after AVR (111-114).

The overall concept is that postoperative survival and LV function will be enhanced if asymptomatic or mildly symptomatic patients with LV dysfunction undergo AVR without waiting for advanced symptomatology or worsening severity of LV dysfunction (115-118).

The indications for AVR can be summarized as follows: appearance of symptoms including angina, dyspnea, presyncope or syncope; extreme LV dilation (end-diastolic dimension at least 65 to 70 mm [normal less than or equal to 55 mm] and end-systolic dimension greater than 55 mm [normal less than or equal to 35 mm]); development of LV systolic dysfunction (ejection fraction below normal at rest); and undergoing coronary artery bypass or surgery on the aorta or other valves (119-124). If these endpoints are adhered to, survival and LV function are optimized. The results are also excellent for LV dilation as long as preoperative LV systolic function is preserved. Asymptomatic patients with normal LV contractile function do not need prophylactic valve replacement.

The difficult problem is symptomatic patients with advanced LV dysfunction (ejection fraction less than 0.25 and end-systolic dimension greater than 60 mm). The high operative risk (mortality less than or equal to 10%) and subsequent

TABLE 29
Grading of aortic regurgitation using colour flow Doppler aortic regurgitation jet diameter versus left ventricular outflow tract (LVOT)

Grade	% aortic regurgitation/LVOT ratio
I	<25%
II	25% to 46%
III	47% to 64%
IV	≥65%

medical management of LV dysfunction provide a better alternative than the higher risks of long term medical management alone.

Medical therapy with afterload reducing agents (nifedipine, hydralazine, angiotensin-converting enzyme inhibitors and nitroprusside) are indicated before established indications for surgery and as a supplement to AVR as noted, for advanced disease and probable irreversible myocardial changes (125,126). Medical therapy should not replace or be a substitute for surgical therapy when appropriate (Tables 30 and 31).

AORTIC ANEURYSMAL DISEASE AND CONCOMITANT AORTIC VALVE DISEASE

Etiology

Diseases of the proximal aorta that play a causative role in the commencement or progression of aortic regurgitation are medial degeneration, Marfan's syndrome, Ehlers-Danlos syndrome or pseudoxanthoma elasticum (127). Atherosclerotic disease may produce aortic regurgitation by annular dilation. Annuloaortic ectasia is a descriptive term for aortic root dilation. Endocarditis of the native or prosthetic valve can cause destruction of the aortic annulus with abscess, aneurysm and fistula formation. Aortic dissection, either acute or chronic, can cause aneurysmal involvement of the proximal aorta and aortic regurgitation.

Marfan's syndrome is an autosomal dominant hereditary disorder of connective tissue involving the skeletal, ocular and cardiovascular systems caused by alterations in the synthesis of fibrillin. Marfan's syndrome is the predominant connective tissue disorder involving the ascending aorta.

Aortic stenosis can be accompanied with poststenotic dilation affecting the greater curvature of the aorta on the right side, possibly related to the jet stream created by the obstructive orifice.

Diagnosis

The pathoanatomy of the aortic root disease and aortic regurgitation can be delineated by various investigative modalities inclusive of echocardiography, computed tomography (CT), magnetic resonance imaging and aortography. The acuity of the clinical circumstances will dictate the diagnostic tool (eg, echocardiography and CT are used for acute dissection of the proximal aorta). Magnetic resonance imaging and aortography can be used for detection of aortic root dilation and geography of the aorta, and status of the proximal coronary anatomy. Aortography and transesophageal echocardiography (TEE) are indicated for detection of fistula of the sinus of Valsalva or aneurysm formation. Aortography is a relative contraindication in acute endocarditis because of the risk of causing septic emboli from catheter manipulation.

Natural history

Aneurysmal formation of the aorta has an increasing risk of rupture or dissection with progressive enlargement (128-132). The average increase is 4.3 mm per year. The average rate of increase in size is 1.7 mm per year for small aneurysms measuring less than 50 mm, 7.9 mm per year for aneurysms greater than 50 mm, and 11.1 mm per year for aneurysms greater than 80 mm. The ascending aorta in Marfan's syndrome may increase more than 5.0 mm per year and there may be a familial risk of dissection at an ascending aorta diameter of less than 50 mm (133).

Indications for surgical intervention

The rationale for elective resection of proximal aortic disease is to prevent the catastrophic occurrence of rupture or dissection. The mandatory indications for surgery are acute dissection of the ascending aorta and spontaneous rupture. The elective indications are to prevent progression of aortic insufficiency and rupture or dissection of the aorta — in Marfan's syndrome related pathology, in the presence of degenerative dilatation of the ascending aorta with or without bicuspid aortic valve and in chronic dissection. The normal diameter of the ascending aorta, aortic sinuses and the aortic annulus correlates with body size and age in men and women (134). Body size is the predominant determinant of the size of the aortic annulus and sinuses of Valsalva while age is the predominant determinant of size of the sino-tubular junction and ascending aorta. The age-related factors are due to fragmentation and loss of elastin in the media. The aortic ratio, defined as measured diameter/predicted diameter at the sinuses determines the relative risk of rupture, dissection or operation for enlarged diameter. The aortic ratio in Marfan's syndrome of 1.3 can translate to a diameter of 40 to 45 mm, much below the upper limit of 50 mm which has been considered the absolute size criterion. A ratio of 1.5 can be considered for dilated aorta due to medial degeneration without significant aortic regurgitation. The bicuspid aortic valve with post-stenotic dilatation can fall between these extremes for definitive treatment on the ascending with a ratio of 1.4 or an approximate diameter of 45 mm. There is a clear relationship between a dilated ascending aorta and a bicuspid aortic valve even in the absence of significant dysfunction of the valve. On the other hand, dilatation of the ascending aorta is currently the most common cause of isolated aortic valvular regurgitation. The aorta is pathologically dilated if the diameter exceeds the norm for a given age and body size (135-137). An aneurysm is defined as a 50% increase over the normal diameter. The most important consequence of an enlarged ascending aortic dimension is the proportional increase in incidence of rupture, dissection and reoperation, the latter especially after valve replacement for a bicuspid valve (138,139).

The choice of procedures includes separate replacement of aortic valve and ascending aorta, composite replacement with a mechanical valved conduit or stentless root bioprosthesis, aortic root wrapping and valve-sparing root replacement, or pulmonary root autograft.

Diseases of the proximal aorta can cause acute regurgitation and also contribute to chronic aortic regurgitation. Valvular regurgitation may be less important to decision-making than primary disease of the aorta (140). When aortic regurgitation is mild or moderate and the left ventricle (LV) is only mildly dilated, management must focus on aortic root disease, but

TABLE 30
Recommendations for aortic valve replacement in chronic severe aortic regurgitation

Indication	Class	
1. Patients with New York Heart Association (NYHA) functional class III or IV symptoms and preserved left ventricular (LV) systolic function, defined as normal ejection fraction at rest (ejection fraction ≥0.50)	I	B
2. Patients with NYHA functional class II symptoms and preserved LV systolic function (ejection fraction ≥0.50 at rest) but with progressive LV dilation or declining ejection fraction at rest on serial studies or declining effort tolerance on exercise testing	I	B
3. Patients with Canadian Cardiovascular Society class II or greater angina with or without coronary artery disease	I	C
4. Asymptomatic or symptomatic patients with mild to moderate LV dysfunction at rest (ejection fraction 0.25 to 0.49)	I	C
5. Patients undergoing coronary artery bypass surgery or surgery on the aorta or other heart valves	I	C
6. Patients with NYHA functional class II symptoms and preserved LV systolic function (ejection fraction ≥0.50 at rest) with stable LV size and systolic function on serial studies and stable exercise tolerance	IIa	C
7. Asymptomatic patients with normal LV systolic function (ejection fraction ≥0.50) but with severe LV dilation (end-diastolic dimension >75 mm or end-systolic dimension >55 mm)*	IIa	C
8. Patients with severe LV dysfunction (ejection fraction <0.25)	IIb	C
9. Asymptomatic patients with normal systolic function at rest (ejection fraction >0.50) and progressive LV dilation when the degree of dilation is moderately severe (end-diastolic dimension 70 to 75 mm, end-systolic dimension 50 to 55 mm)	IIb	C
10. Asymptomatic patients with normal systolic function at rest (ejection fraction >0.50) but with decline in ejection fraction during exercise radionuclide angiography	IIb	C
11. Asymptomatic patients with normal systolic function at rest (ejection fraction >0.50) but with decline in ejection fraction during stress echocardiography	IIb	C
Contraindication		
12. Asymptomatic patients with normal systolic function at rest (ejection fraction >0.50) and LV dilation when degree of dilation is not severe (end-diastolic dimension <70 mm, end-systolic dimension <50 mm)	III	C

**Consider lower threshold values for patients of small stature of either sex. Clinical judgement is required. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29)*

TABLE 31
Recommendations for vasodilator therapy for chronic aortic regurgitation (AR)

Indication	Class	
1. Chronic therapy in patients with severe regurgitation who have symptoms and/or left ventricular (LV) dysfunction when surgery is not recommended because of additional cardiac or noncardiac factors	I	C
2. Long term therapy in asymptomatic patients with severe regurgitation who have LV dilation but normal systolic function	I	C
3. Long term therapy in asymptomatic patients with hypertension and any degree of regurgitation	I	C
4. Long term angiotensin-converting enzyme inhibitor therapy in patients with LV systolic dysfunction after aortic valve replacement (AVR)	I	C
5. Short term therapy to improve the hemodynamic profile of patients with severe heart failure symptoms and severe LV dysfunction before proceeding with AVR	I	C
Contraindication		
6. Long term therapy in asymptomatic patients with mild to moderate AR and normal LV systolic function	III	C
7. Long term therapy in asymptomatic patients with LV systolic dysfunction who are otherwise candidates for valve replacement	III	C
8. Long term therapy in symptomatic patients with either normal LV function or mild to moderate LV systolic dysfunction who are otherwise candidates for valve replacement	III	C

Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29)

must be inclusive of altered valvular function. When the aortic regurgitation is severe and associated with severe LV dilation or systolic dysfunction, the timing of surgical intervention must accommodate both conditions.

AVR and aortic root reconstruction are indicated for disease of the proximal aorta and aortic regurgitation of any severity when (or before) the degree of aortic root dilation is at least 50 mm (141-145). In Marfan's syndrome, surgery is recommended when the root diameter reaches 45 to 50 mm because of the risk of acute dissection or aneurysm rupture (146-154). Family history strongly reinforces the decision for surgery because 20% of patients develop dissection before the root diameter reaches 50 mm.

Aortic aneurysm of the proximal aorta may accompany aortic stenosis but not involve the aortic root (155). Poststenotic dilation may involve the proximal aorta in aortic stenosis. An ascending aortic aneurysm of 45 mm should be considered for replacement at the appropriate timing of AVR for aortic stenosis. A measurement of greater than 40 mm is a measure of the ascending aorta because a diameter of 40 mm may be observed at the sinus of Valsalva in a normal sized adult. An ascending aortic aneurysm of greater than 55 mm must dictate the timing of surgery regardless of the severity of aortic stenosis. Indications for AVR remain similar whether these are primary or secondary reasons for surgery. Mild aortic stenosis accompanying proximal aortic disease is a relative indication for AVR because of the risk of subsequent surgery. Bicuspid aortic stenosis in middle age with an aorta diameter of 40 to 45 mm may be managed with a composite valved conduit graft because the aorta will dilate.

Surgical treatment options

Annuloaortic ectasia is usually managed with aortic root reconstruction using either a mechanical valve conduit, allograft (homograft) aortic root or stentless porcine aortic root, inclusive of coronary artery/aortic wall button reanastomoses (156). When the aortic valve is morphologically near normal, the pathological aorta can be replaced with a valve-sparing operation using a nontailored or tailored tubular synthetic graft (157-163).

The valve-sparing operation with a nontailored graft is a re-implantation procedure that corrects annuloaortic ectasia (as in Marfan's syndrome) and dilation of the sinotubular junction (164-167). The remodelling procedure is optimal for dilated sinuses and the dilated sinotubular junction without annular disease (168-170). The remodelling operation incorporates the proximal aortic wall including commissures and valve leaflets (171). Coronary ostial button anastomoses are performed in both techniques. The remodelling can incorporate partial annuloplasty if there is dilation of the fibrous skeletal portion of the annulus, or full annuloplasty in Marfan's syndrome. When only the sinotubular junction is dilated and the valve is not overstretched and abnormal, the operation can be valve replacement and supracoronary graft.

The valve-sparing operations are currently indicated for aneurysms of the ascending aorta and root (greater than 50 to 60 mm) and the tricuspid valve without gross structural defect, absence of severe cusp prolapse or asymmetry, with or without valve insufficiency. These valve-sparing procedures are usually performed with a trileaflet aortic valve. To date, there is very preliminary experience with bicupsid valve morphology (172,173).

Poststenotic aortic dilation can be managed conservatively with a tailoring procedure or tubular synthetic graft replacement.

The prosthesis-type options for AVR for aortic stenosis or aortic regurgitation by adult age groups are detailed in Table 32.

The choice of prosthesis is a decision made by the surgeon and the patient (174-178). The patient should be advised of the risks and advantages of the prostheses (179-189).

Fifteen-year outcomes after replacement with a mechanical or bioprosthetic valve are reported by the Veterans Affairs randomized trial (183). At 15 years, patients undergoing AVR had better survival with a bioprosthetic valve than with a mechanical valve, even though structural valve deterioration was virtually absent with the mechanical valve. Structural valve deterioration was greater with a bioprosthesis for AVR and occurred at a much higher rate in those aged less than 65 years. In patients at least 65 years of age, structural valve deterioration after AVR was not significantly different between the bioprosthesis and the mechanical prosthesis. Reoperation was more common for AVR with the bioprosthesis. Thromboembolism rates were similar with the two-valve prosthesis, but bleeding was more common with the mechanical prostheses.

The Edinburgh randomized trial reported in 2003 results to 20 years (184). The prosthesis type did not influence survival, thromboembolism or endocarditis. Major bleeding was more common with mechanical prosthesis. Assessing mortality and reoperation, survival with original prosthesis became different at eight to 10 years for MVR and 12 to 14 years for AVR.

There is sufficient evidence to recommend bioprostheses, porcine or pericardial, for patients at least 65 years of age. The evidence pertains to both first and second generation heterograft stented bioprostheses (190-205). The actual freedom (cumulative incidence) from structural valve deterioration at 15 years is 87% for 61 to 70 years of age and 96% for greater than 70 years of age; the actuarial freedom is 76% and 82%, respectively (205-208). The freedom from structural valve deterioration does not warrant bioprosthesis use in patients below 60 to 65 years of age (209,210).

The mechanical prostheses currently marketed are free from structural failure (211-213). The linearized rates of major thromboembolism and hemorrhage in patients less than 65 years of age are both approximately 1.5% per patient year. The literature provides a variation of results dependent on follow-up methodology, adequacy of follow-up, and exclusion or inclusion of events up to 30 days (186,212,214-220). The rates of thromboembolism and hemorrhage for patients at least 65 years of age are higher (221). The freedom from major or fatal TE, thrombosis and hemorrhage is 90% at five years for patients less than 65 years of age (221).

The optimal prosthesis type for valve replacement in patients on chronic renal dialysis is unresolved. In 1998, the ACC/AHA continued to recommend mechanical prostheses (31). The publications since 1998 have overwhelmingly recommended bioprostheses (222-225). It was considered that patients on chronic dialysis do not generally survive long enough to experience structural valve deterioration. The two-year survival was only 39% for both bioprostheses and mechanical prostheses, which is poor for both prosthesis types (223). Mechanical prostheses have been shown to have a sixfold higher incidence of late bleeding or stroke (222).

Allografts are recommended for aortic valve disease as a subcoronary implantation or aortic root replacement (227-232). Allografts have provided acceptable results up to 25 years (233-236). The actuarial freedom from structural valve deterioration at 12 years was 91% for 20 to 39 years, 91% for 40 to 59 years and 89% for greater than 60 years (237). Additional allograft experience has demonstrated a 10-year freedom from structural valve deterioration of 97%. The most recently reported experience of allografts over a duration of 29 years has differentiated the indications (238). The report has recommended allografts in patients over 20 years of age because the freedom from reoperation for structural failure at 10 years in patients less than 20 years of age was only 47% (238). The homovital allografts, in contradistinction to the cryopreserved allografts, demonstrates a freedom from structural valve deterioration at 10 years of 97% for patients at least 30 years of age (239). The major deterrent to the use of allografts is the general limited availability. It is for this reason that allografts are used primarily in the management of infective, native and prosthetic endocarditis, especially in cases with destructive annular disease, inclusive of discontinuity, abscesses and fistulas (see section XIV: Infective endocarditis). The allograft root replacement is also recommended for aortic aneurysmal dilation with valve incompetence and severe LVOT or tunnel stenosis. The allograft aortic root replacement provides the opportunity for less likelihood of distortion in cases of asymmetry and bicuspid disease, and makes size matching less critical (240-242).

Autografts are usually reserved for the younger patient and the very active (competitive sports) patient (228,229,235,243-246). These patients require ongoing follow-up. The contraindications to the use of autografts must be respected to avoid structural failure. The contradictions are connective tissue disorders (ie, Marfan's syndrome), immunological disorders, and bicuspid or fenestrated pulmonary valves. The autograft has the advantage of somatic growth and thus is ideal in the pediatric age group (see section VI: Congenital valve disease). For autograft aortic root replacement, the pulmonary allograft is used for reconstruction of the RV outflow tract because it is more durable than the aortic allograft (242).

The autograft is safe and reproducible in overall hemodynamic and durability performance in properly selected young adults (232,247-255). There have been two documented concerns with the autograft procedure. There is an incidence of late pulmonary allograft stenosis attributed to younger donor age, shorter duration of cryopreservation and smaller homograft size (256). The other concern is late dilation of the autograft involving the root, sinuses of Valsalva and sinotubular junction (257). Dilation of the sinotubular junction, and not the sinuses, causes aortic regurgitation (258-259). The dilation has been attributed to accompanying pulmonary wall pathology in bicuspid aortic valve morphology and other congenital anomalies. This has been attributed to histological abnormalities of the aortic and pulmonary roots, with common embryogenesis, in conjunction with bicuspid aortic valve disease. There is contradictory evidence demonstrating that the abnormalities of the pulmonary artery are the same with bicuspid and tricuspid aortic valves. Root dilation is relatively common after autograft root replacement but unrelated to bicuspid aortic valve disease (260). The latter investigation has demonstrated no correlation between bicuspid aortic valves, degenerative changes of the pulmonary artery and autograft root aneurysm. It is felt that degenerative changes of the pulmonary artery root are negligible and similar in bicuspid and tricuspid aortic valves undergoing autograft procedure. There is consideration that other factors play a role in autograft dilation.

There are surgical alternatives to deal with this issue. Abandon autograft root replacement in the bicuspid aortic valve, perform only subcoronary or root inclusion, or buttress the annulus, coronary artery buttons and sinotubular junction. This technique may be inappropriate in children where somatic growth is desirable. The autograft is contraindicated if the aortic annulus is greater than 30 mm.

The autograft has better durability and hemodynamics than the cryopreserved allograft. The trend favouring the autograft over the allograft occurs at eight years of evaluation. Continuing research in the use of autografts is imperative.

Stentless bioprostheses have been shown to have better hemodynamics than stented bioprostheses and mechanical prostheses. This is likely related to the ability to implant a larger prosthesis and lack of support structure. The stentless design may increase long term freedom from structural valve degeneration and potentially improve survival (261).

The use of small size prosthesis is controversial. There is evidence of significant residual gradients with valve sizes 19 and 21 with the majority of stented bioprostheses and mechanical prostheses. The sewing cuff configurations of small aortic mechanical prostheses and external mounted pericardial bioprostheses have been designed to address these issues. The stentless bioprostheses also address this issue (262-272).

TABLE 32
Prosthesis options for aortic valve replacement

Age range (years)	Prosthesis type
20 to 40	Pulmonary autograft (no contraindication, ie, annuloaortic ectasia)
	Mechanical prosthesis
	Allograft (if contraindication to autograft or anticoagulation)
41 to 64	Mechanical prosthesis
	Stentless heterograft prosthesis
	Stented heterograft prosthesis
	Pulmonary autograft (to 55 years if good candidate)
	Allograft
65 and older	Stented heterograft porcine or pericardial (specifically if large annulus)
	Stentless heterograft subcoronary implantation
	Allograft or stentless porcine root (specifically if small annulus or calcified root)
	Mechanical prosthesis

The optimization of hemodynamic performance of valvular substitutes in AVR has always been recognized as being of extreme importance, and is of recent consideration because it may relate to long term patient survival (273-279). The important objective of AVR is to minimize postoperative gradients and to optimize the normalization of LV mass and function (280-292). The most frequent cause of high postoperative gradients is when the effective prosthetic valve area is less than that of the normal human valve. This is commonly known as patient-prosthesis mismatch, even in the presence of a normally functioning valve prosthesis (293). Patient-prosthetic mismatch occurs when indexed effective orifice area (EOA) is reduced, ie, the size of the prosthesis orifice is too small in relation to the patient's body size or body surface area (294). It has been demonstrated that to avoid any significant gradient at rest or exercise, the indexed EOA of the aortic valve prosthesis should ideally be no less than 0.85 to 0.90 cm^2/m^2 (280-286). This is in keeping with the concept of moderate aortic stenosis of the native aortic valve, when the indexed EOA is less than 0.90 cm^2/m^2 (293-302).

When selecting a prosthesis for a given patient, surgeons should consider the potential for patient-prosthesis mismatch, as assessed by optimal effective orifice indexes (303-306). The objective of AVR is to ensure that the indexed EOA after operation is above levels to avoid residual stenosis. Suboptimal effective orifice indexes may not present a risk to the less active older population but may influence survival in the younger population although there is no significant evidence at the present time. (Tables 33 and 34).

Special surgical considerations

The role of the autograft is evolving. Although the autograft is reserved for the young person, it should not be used in the young patient with rheumatic heart disease when there is mitral involvement. It has been considered contraindicated in the young patient with bicuspid aortic morphology and annuloaortic ectasia. Aortic root replacement may not be recommended because the autograft may not tolerate systemic pressures for a prolonged period of time.

TABLE 33
Recommendation for valve replacement with a mechanical prosthesis

Indication	Class	
1. Patients with expected long lifespans	I	B
2. Patients with a mechanical prosthetic valve already in place in a different position than the valve to be replaced	I	B
3. Patients requiring warfarin therapy because of risk factors* for thromboembolism	IIa	C
4. Patients ≤65 years for AVR and ≤70 years for MVR	IIa	C
5. Valve replacement for thrombosed biological valve	IIb	C
Contraindication		
6. Patients in renal failure, on hemodialysis, or with hypercalcemia	III	C
7. Patients who cannot or will not take warfarin therapy	III	C

**Risk factors: atrial fibrillation, severe left ventricular dysfunction, previous thromboembolism, and hypercoagulable condition; The age at which patients may be considered for bioprosthetic valves is based on the major reduction in rate of structural valve deterioration after age 65 and the increased risk of bleeding in this age group. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29)*

TABLE 34
Recommendations for valve replacement with a bioprosthesis

Indication	Class	
1. Patients who cannot or will not take warfarin therapy	I	C
2. Patients ≥65 years* needing AVR who do not have risk factors for thromboembolism	I	B
3. Patients considered to have possible compliance problem with warfarin therapy	IIa	C
4. Patients >70 years* needing MVR who do not have risk factors for thromboembolism	IIa	B
5. Valve replacement for thrombosed mechanical valve	IIb	C
6. Patients <65 years*	IIb	C
7. Patients in renal failure, on hemodialysis, or with hypercalcemia	IIa	C
Contraindication		
8. Adolescent patients who are still growing	III	C

**The age at which patients should be considered for bioprosthetic valves is based on the major reduction in rate of structural valve deterioration after age 65 and increased risk of bleeding in this age group; Risk factors: atrial fibrillation, severe LV dysfunction, previous thromboembolism, and hypercoagulable condition. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (29). AVR Aortic valve replacement; MVR Mitral valve replacement*

The concomitant aortic root of 45 to 50 mm and normal tricuspid aortic valve in Marfan's disease can be managed with earlier operation. If an aortic root replacement or repair is needed, a root diameter greater than 50 mm is the indication for surgery. Aortic annuloplasty of the large annulus with the remodelling procedure may have the same durability as the reimplantation, modelling aortic reconstruction and coronary reimplantation.

The small aortic root can be managed by either stentless bioprosthesis, supra-annular noncoronary sinus implantation (advantage: one size) of stented bioprosthesis, or patch enlargement of the noncoronary sinus and anterior leaflet of the mitral valve (advantage: possibly two sizes).

The calcified aortic root requires complete resection and reconstruction. The risk is increased by the presence of a calcified arch, as well as a calcified intervalvular fibrous body.

Aortic stenosis and poststenotic dilation should be addressed with a reconstructive procedure if the root is dilated to 40 mm to 45 mm. Supracoronary replacement of the aorta is needed if the root is normal. In the elderly, tailoring and Dacron wrapping of the aorta can be considered an acceptable alternative.

The patient with mild or moderate aortic stenosis undergoing coronary artery bypass requires exploration of the valve. If the leaflets are calcified and fibrotic, they can be replaced with a stented or stentless bioprosthesis because the aortic root is frequently normal.

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SECTION IV: MITRAL VALVE AND CONCOMITANT AORTIC AND TRICUSPID DISEASE

MITRAL STENOSIS

Etiology

The predominant cause of mitral stenosis presenting in adulthood is injury sustained from prior rheumatic fever.

Pathophysiology

Mitral stenosis causes obstruction at the level of the mitral valve during diastolic filling of the LV (1). The pathological process causes leaflet/chordal thickening and calcification, commissural fusion or shortening, chordal fusion or a combination of these processes.

The normal MVA is 4.0 to 5.0 cm^2. Patients with a MVA greater than 2.5 cm^2 are generally asymptomatic both at rest and with exercise. MVA greater than 1.5 cm^2 usually does not produce symptoms at rest. When the MVA is between 1.5 to 2.5 cm^2, symptoms, usually dyspnea, may occur with increased transmitral flow (eg, exercise, emotional stress, infection, pregnancy) or a decreased diastolic filling period (eg, uncontrolled atrial fibrillation) (2). Accordingly, mild mitral stenosis is defined as a MVA of 1.5 to 2.5 cm^2 and a mean gradient at rest less than 5 mmHg. Moderate and severe mitral stenosis are defined as an MVA 1.0 to 1.5 cm^2 and less than 1.0 cm^2, respectively, with mean gradients greater than 5 mmHg. Pulmonary hypertension frequently complicates mitral stenosis. There is an increase in RV end-diastolic volume and pressure as well as secondary tricuspid regurgitation. The onset of atrial fibrillation can cause abrupt deterioration.

Natural history

Mitral stenosis is a continuous, progressive, lifelong disease. There is a long latent period of 20 to 40 years from occurrence of rheumatic fever to the onset of symptoms (3). Following the development of symptoms, limitation may not be disabling for a decade. The survival at 10 years in the asymptomatic and minimally symptomatic patient is greater than 80%. When disabling symptoms occur, 10-year survival is at least 15%. The survival drops to less than three years when severe pulmonary hypertension occurs. In North America and Europe, the mean age at presentation is now the fifth to sixth decade.

Diagnosis

The echocardiographic guidelines are detailed in section XI. The hemodynamic severity of mitral valve obstruction should be assessed with Doppler echocardiography (4). The parameters to be measured include resting mean transmitral gradient, MVA and pulmonary artery systolic pressure. The mean gradient is measured from the continuous wave Doppler signal across the mitral valve. MVA can be noninvasively measured by either the diastolic pressure half-time, two dimensional orifice planimetry or continuity equation. A diastolic pressure half-time of greater than 220 msec determined from the transmitral flow velocity curve obtained from continuous wave Doppler echocardiography is considered severe.

Indications for intervention

Open commissurotomy (valvuloplasty) is the accepted surgical procedure which facilitates under direct vision, division of the commissures, splitting of fused chordae tendineae and papillary muscles, and debridement of calcium deposits (5). Obliteration of the LA appendage is also recommended. The five-year reoperation rate is approximately 5% and the five-year complication-free survival rate is 80% to 90%.

Percutaneous mitral balloon valvotomy (PMBV) is a frequent initial therapeutic option for patients with mitral stenosis (6-9). The underlying mitral valve morphology is the most important factor in determining outcome, acute complications and rate of recurrent stenosis on follow-up. Accordingly, an echocardiographic scoring system (Wilkins score) has been developed to assess suitability and predict outcome of PMBV. The morphological appearance of the mitral valve apparatus is assessed by two-dimensional echocardiography, including leaflet thickness and mobility, commissural calcification and degree of subvalvular fusion. Each of these parameters is subjectively scored from one (least severe) to four (most severe) and a total score out of 16 is reported. Patients with a mitral valve score of eight or less and no more than mild (2+) mitral regurgitation have been shown to have the best results from PMBV (10). Heavy echogenicity at the commissures due to calcification is a predictor of poor outcome and is not adequately covered by the Wilkins score (11-14).

A transesophageal echocardiogram (TEE) should invariably be performed immediately before PMBV. The role of TEE in PMBV is to determine the presence of thrombus in the left atrium; this leads to a change in patient management, including PMBV delay or cancellation. In selected cases where transthoracic echocardiography (TTE) provides suboptimal information, a TEE can also be useful to evaluate mitral valve morphology and hemodynamics. (Table 35).

The intermediate results of percutaneous mitral valvotomy are similar to open mitral valvuloplasty (15-17). The MVA usually doubles (from 1.0 to 2.0 cm^2) with a 50% to 60% reduction in transmitral gradient. A successful procedure is defined as an MVA greater than 1.5 cm^2 and a decrease in LA pressure to 18 mmHg. This is achieved in 80% to 95% of patients (18-22). The mortality in large series by experienced interventionalists is 1% to 2%. The significant complications are severe mitral regurgitation and residual atrial septal defect (23-27).

The mitral valve morphology is the factor of greatest importance in determining outcome. The five- to seven-year freedom from death or repeat valvotomy or MVR is 80% to 90% with favourable morphology (18,19,28-31). As stated, the relative contraindications are LA thrombus and 3 to 4+ mitral regurgitation. The indications for the procedure include patients with symptomatic and asymptomatic moderate or severe mitral stenosis with pulmonary hypertension or new onset atrial fibrillation (32). Due to the less invasive nature of the procedure, asymptomatic patients and those with NYHA class II symptoms are considered appropriate.

The indications for mitral valve repair (open mitral valvuloplasty) are similar to mitral balloon valvotomy except asymptomatic and class II patients are not considered (33-36) (Table 36).

MVR is indicated when patients with moderate or severe mitral stenosis and advanced symptomatology are not candidates for balloon valvotomy or open mitral valvuloplasty (37-40). Although there is some controversy, valve replacement is generally recommended for asymptomatic or mildly symptomatic patients with severe mitral stenosis and marked pulmonary hypertension to prevent RV failure (41).

TABLE 35
Recommendations for percutaneous mitral balloon valvotomy

Indication	Class	
1. Symptomatic patients (New York Heart Association [NYHA] functional class II,III, or IV), moderate or severe mitral stenosis (MS) (mitral valve area ≤1.5 cm^2)* and valve morphology favourable for percutaneous balloon valvotomy in the absence of left atrial thrombus or moderate to severe mitral regurgitation (MR)	I	B
2. Asymptomatic patients with moderate or severe MS (mitral valve area ≤1.5cm^2)* and valve morphology favourable for percutaneous balloon valvotomy who have pulmonary hypertension (pulmonary artery systolic pressure >50 mmHg at rest or >60 mmHg with exercise) in the absence of left atrial thrombus or moderate to severe MR	IIa	C
3. Patients with NYHA functional class III to IV symptoms, moderate or severe MS (mitral valve area ≤1.5 cm^2),* and a nonpliable calcified valve who are at high risk for surgery in the absence of left atrial thrombus or moderate to severe MR	IIb	
4. Asymptomatic patients, moderate or severe MS (mitral valve area ≤1.5 cm^2)* and valve morphology favourable for percutaneous balloon valvotomy who have new onset of atrial fibrillation in the absence of left atrial thrombus or moderate to severe MR	IIb	C
Contraindication		
5. Patients in NYHA functional class III to IV, moderate or severe MS (mitral valve area ≤1.5 cm^2) and a nonpliable calcified valve who are low-risk candidates for surgery	III	C
6. Patients with mild MS	III	C

**The committee recognizes that there may be variablity in the measurement of mitral valve area and that the mean transmitral gradient, pulmonary artery wedge pressure and pulmonary artery pressure at rest or during exercise should also be taken into consideration. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (9)*

TABLE 36
Recommendations for mitral valve repair for mitral stenosis (MS)

Indication	Class	
1. Patients with New York Heart Association (NYHA) functional class III to IV symptoms, moderate or severe MS (mitral valve area ≤1.5 cm^2),* and valve morphology favourable for repair if percutaneous mitral balloon valvotomy is not available	I	C
2. Patients with NYHA functional class III to IV symptoms, moderate or severe MS (mitral valve area ≤1.5 cm^2)* and valve morphology favourable for repair if a left atrial thrombus is present despite anticoagulation	I	C
3. Patients with NYHA functional class III to IV symptoms, moderate or severe MS (mitral valve area ≤1.5 cm^2)* and a nonpliable or calcified valve with the decision to proceed with either repair or replacement made at the time of the operation	I	B
4. Patients with NYHA functional class I to II symptoms, moderate or severe MS (mitral valve area ≤1.5 cm^2)* and valve morphology suitable for repair or replacement, and atrial fibrillation duration < 3 months (likelihood of conversion to normal sinus rhythm)	IIa	C
5. Patients in NYHA functional class I, moderate or severe MS (mitral valve area ≤1.5 cm^2)* and valve morphology favourable for repair who have had recurrent episodes of embolic events on adequate anticoagulation	IIb	C
Contraindication		
6. Patients with NYHA functional class I to IV symptoms and mild MS	III	C

**The committee recognizes that there may be a variability in the measurement of mitral valve area and that the mean transmitral gradient, pulmonary artery wedge pressure and pulmonary artery pressure at rest or during exercise should also be considered. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (9)*

The risk of MVR is dependent on multiple factors including functional status, age, ventricular function and comorbid medical problems including CAD (42). The risk of early mortality is 5% in young patients and may be as high as 10% to 20% with advancing age and comorbid disease. (Table 37).

MITRAL REGURGITATION

Natural history

Long term survival from mitral regurgitation is poorly delineated with wide variation of reported results (9,43,44). Severe mitral regurgitation due to flail leaflets has been reported to have a mortality of 6.3% per year. The 10-year incidence of atrial fibrillation was 30% and of congestive heart failure was 63%. At 10 years, 90% of patients had died or undergone surgery. For patients who did not have surgery, the mortality was 34% per year with NYHA III or IV symptoms and 4.1% per year for NYHA I or II symptoms. The mortality varied considerably for ejection fraction less than 60% versus greater than 60%.

Etiology

The common causes of isolated chronic mitral regurgitation are related to myxomatous degeneration, calcific disease of the elderly and functional disorders. Calcification of the annulus is common in the elderly but is seldom a cause of severe mitral regurgitation. The other causes include rheumatic heart disease, infective endocarditis and Marfan's syndrome. The functional causes are ischemia, dilated cardiomyopathy, infiltrative or restrictive cardiomyopathy, and hypertrophic cardiomyopathy.

Pathophysiology

Acute severe mitral regurgitation: The sudden volume overload results in pulmonary congestion because both the unprepared left atrium and left ventricle cannot accommodate the regurgitant volume. The pulmonary congestion is accompanied by reduced forward flow and cardiogenic shock.

Chronic severe mitral regurgitation: Chronic mitral regurgitation is a progressive disorder with LV dilation and hypertrophy

TABLE 37
Recommendations for mitral valve replacement for mitral stenosis (MS)

Indication	Class	
1. Patients with moderate or severe MS (mitral valve area ≤1.5 cm^2)* and New York Heart Association (NYHA) functional class III to IV symptoms who are not considered candidates for percutaneous balloon valvotomy or mitral valve repair	I	B
2. Patients with severe MS (mitral valve area ≤1 cm^2)* and severe pulmonary hypertension (pulmonary artery systolic pressure >60 to 80 mmHg) with NYHA functional class I to II symptoms who are not considered candidates for percutaneous balloon valvotomy or mitral valve repair	I	B

**The committee recognizes that there may be a variability in the measurement of mitral valve area and that the mean transmitral gradient, pulmonary wedge pressure and pulmonary artery pressure should also be considered. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (9)*

to accommodate increasing regurgitant volume (45-52). The regurgitant volume leads to enlargement of the left atrium, which leads to dilation of the valve annulus and worsening of leaflet coaptation. The LV end-diastolic volume increase is compensated by the low impedance to ejection into the compliant left atrium, so end-systolic volume remains near normal and ejection fraction is maintained. During this compensatory phase, pulmonary congestion is abated. The duration of the compensated phase of mitral regurgitation may last for many years.

As the severity of mitral regurgitation increases, the ventricle continues to dilate which leads to increases in systolic wall stress and end-systolic volume with LV dysfunction. These hemodynamic conditions result in pulmonary congestion. The ejection fraction may be maintained at a low normal range of 50% to 60%.

The advanced stage of decompensation can result in irreversible LV changes. LV function is the most powerful predictor of postoperative outcome. Excessive LV dilation and systolic dysfunction contribute to a greater fall in ejection fraction after surgery with increased evidence of heart failure. There are significant differences in postoperative survival at 10 years between ejection fractions of 60%, 50% to 59% and less than 50% (53-56). Other predictors of poor outcome are advanced age, renal insufficiency, systemic hypertension, significant CAD and failure to preserve the subvalvular apparatus when replacing the valve.

Diagnosis

The echocardiographic guidelines are detailed in section XI. There is no single echocardiographic parameter that allows reliable semiquantification of mitral regurgitation in all cases (57,58). In general, two-dimensional echocardiography is used to describe the mechanism and address the potential surgical reparability of a leaky valve, while various Doppler based parameters are available for semiquantification of mitral regurgitation severity. As for all valvular lesions, it is essential to consider the entire echocardiographic picture, including chamber dimensions, ventricular function, structure of the mitral valve, Doppler measurements, as well as temporal changes in these parameters.

Symptoms and left ventricular dysfunction generally occur when regurgitant fraction (mitral regurgitation volume/total LV stroke volume) exceeds 40% to 50%. The classification of mitral regurgitation severity is outlined in Table 38.

The classification assumes the patient is in a stable state with regard to afterload, preload and contractility. Trace or mild mitral regurgitation with a structurally normal mitral valve may represent normal variants in subjects without valvular dysfunction. Selected patients with mild, and most patients with moderate and severe mitral regurgitation warrant consideration of surgical therapy.

TABLE 38
Classification of mitral regurgitation severity

Degree	Regurgitant fraction (%)
Trace (0)	<10
Mild (1+)	10 to 29
Moderate (2+ to 3+)	30 to 50
Severe (4+)	>50

Mitral regurgitation relates to deficiency in leaflet free edge apposition and effective coaptation (59,60). Mitral regurgitation can be due to structural or functional abnormalities, the motion of the free edge being either normal (type I), excessive (prolapse or type II) or restricted (type III). The organic causes are dilation of the annulus and leaflet perforation (type I) or, in the case of prolapse (type II), elongation or rupture of the chordae tendinae or papillary muscle. In the case of restricted leaflet motion (LM) (type IIIa), the lesions are thickened leaflet tissue and restricted and thickened chordae or papillary muscle. The ischemic or functional regurgitation (type IIIb) is due to the combination at varying degrees of an increase of the sphericity index of the LV, a displacement of the papillary muscles, an increase in the tethering forces of the leaflets, a diminution of the closing forces and a lack of annulus contraction.

The severity of mitral regurgitation can be assessed by several parameters using echocardiography, including colour flow mapping, PISA, quantitative Doppler flow and vena contracta width (58).

The severity and mechanism of mitral regurgitation can be determined by TEE. Mitral regurgitation severity can be assessed semiquantitatively through planimetry of the colour flow Doppler mitral regurgitation jet in the left atrium, interpreted in isolation as an area in cm^2 or as a ratio of LA area in the same view. A newer approach is to measure the vena contracta width (narrowest diameter of the mitral regurgitation jet by colour flow Doppler as it emerges from the mitral regurgitant orifice). Currently, the vena contracta is believed to correlate best with mitral regurgitation severity, while the mitral regurgitation jet to LA area ratio is probably least accurate. The amplitude and shape of the continuous wave Doppler mitral regurgitation jet signal are also useful. A more quantitative measure is the PISA method. Pulmonary venous systolic flow reversal is also useful in distinguishing moderately severe versus severe degrees of mitral regurgitation. Interrogation of the entire coaptation line from medial to lateral is necessary to evaluate the regurgitant jet(s). The assessment must evaluate location of origin of jet(s) at the coaptation line and then jet direction. The mechanism of regurgitation may be classified as

TABLE 39
Classification of mitral regurgitation (MR): MR index

Degree of MR	MR index
Trace	<1.0
Mild	1.0 to 1.4
Moderate	1.5 to 2.0
Severe	>2.0

due to normal, excessive or restricted LM. Severe mitral regurgitation can be defined as 60 mL/beat for regurgitant volume, 50% for regurgitant fraction and 0.4 cm^2 for effective regurgitant orifice area.

The mitral regurgitation index is a composite of six echocardiographic variables: colour Doppler regurgitant jet area in the left atrium, PISA radius, continuous wave Doppler characteristics of the regurgitant jet and tricuspid regurgitant jet-derived PAP, pulse wave Doppler pulmonary venous flow pattern, and two-dimensional echocardiographic estimation of LA size. Each variable is scored on a four-point scale from zero to three, the individual scores are added and the average is calculated. Using TTE, mitral regurgitation can be classified by the mitral regurgitation index, as shown in Table 39.

Indications for intervention

Mitral valve repair (reconstruction), conventional MVR and MVR with preservation of the subvalvular apparatus (posterior and optimally anterior) are the mitral procedures performed. In severe mitral regurgitation with NYHA III or IV symptoms, there is no controversy about indications for surgery (1,9,61-65). Significant mitral regurgitation in organic degenerative disease, in the absence of significant symptoms, can be problematic; the risk of surgery must be weighed against the risk of delaying surgery and the development of LV dysfunction, which impairs long term survival and quality of life (61,65-69). There is recent evidence that asymptomatic (class I/II) patients have better long term survival than symptomatic (class III/IV) patients with the same risk of reoperation if low risk reparative surgery is possible.

The parameters that predict poor outcome in patients with chronic mitral regurgitation are ejection fraction less than 60%, end-systolic volume index greater than 60 mL/m^2, and end-systolic diameter greater than 45 mm or 26 mm/m^2 (70-72). After valve replacement, patients with a preoperative ejection fraction less than 60% have greater likelihood of developing a postoperative ejection fraction less than 50% and heart failure after surgery. Ejection fraction less than 60% is indicative of LV dysfunction. Mitral valve repair or replacement with preservation of the subvalvular apparatus diminishes the magnitude of postoperative reduction in ejection fraction (73-81). Accurate and reproducible measurements of ventricular volumes, dimensions and ejection fraction are essential for decision-making (82).

Patients with an ejection fraction less than 60% or end-systolic diameter of 45 mm or greater have LV dysfunction and require urgent operation if there is no major comorbidity present (83). Patients with severe mitral regurgitation and depressed ejection fraction, resembling dilated cardiomyopathy and functional mitral regurgitation, could have surgery because the operative mortality may be below 10% (84). There is growing evidence that reduction annuloplasty may be beneficial in patients with severe mitral regurgitation and depressed ejection fraction but mortality is high if mitral replacement is required and there is unlikely to be a benefit in outlook or symptoms (85-89). The best outcome is in patients with ejection fraction of greater than or equal to 60% because of low postoperative incidence of congestive heart failure; the survival at 10 years is equivalent to that expected for a matched population (90-92).

Congestive heart failure postoperatively occurs primarily in those with preoperative severe symptoms and low ejection fraction (93). Patients with ejection fraction of 60% and minimal symptoms have better survival rates than patients with severe symptoms. If preoperative atrial fibrillation has been present for more than three months, there is a high incidence of persistence of atrial fibrillation after surgery. The availability of valve repair and low operative mortality are crucial in the decision-making process. The reparability of ruptured posterior chordae should be 85% to 90% in degenerative disease (94). It has been shown that early surgery with a low perioperative mortality improves morbidity and long term survival (94-102). Long term residual regurgitation may be related to progressive pathological changes (103).

The surgical management of nonischemic mitral regurgitation is complex. Rheumatic mitral regurgitation usually accompanies stenosis and is more likely to be managed by replacement than reconstruction or repair (104-106). The management of degenerative disease is primarily reconstruction (107-111). The elements of mitral valve reconstruction or repair for degenerative disease are posterior leaflet quadrangular resection with or without sliding plasty, triangular resection of the anterior leaflet, chordal transfer, chordal shortening and chordal replacement with artificial expanded polytetrafluoroethylene sutures (75,85,112-138) (Table 40).

ISCHEMIC MITRAL REGURGITATION

Pathophysiology

Mitral incompetence caused by ischemic heart disease must not be confused with mitral incompetence associated with ischemic heart disease. The outlook for the patient with ischemic mitral regurgitation is worse than with other forms of mitral regurgitation. Ischemic mitral regurgitation is usually caused by regional or global LV dysfunction resulting from myocardial infarction (139,140). The one exception is ruptured papillary muscle, an acute catastrophic event.

Ischemic mitral regurgitation can be divided into two forms: structural and functional.

Structural: Structural causes are papillary rupture (complete or partial) and papillary elongation. Of all patients with severe mitral regurgitation in the early stages of myocardial infarction, 50% have suffered an actual rupture. One-third of patients with rupture have complete disruption (leading to flailing of both leaflets and massive mitral regurgitation) and two-thirds have rupture of one or more heads of a papillary muscle.

Functional: Functional causes are due to ventricular dysfunction with normal valvular apparatus (141-146). Stunning, hibernation or infarction leads to three-dimensional changes of the LV cavity with an increase of the sphericity index of the LV, a displacement of the papillary muscles, an increase in the tethering forces of the leaflets, a diminution of the closing forces and a lack of annular contraction. This phenomenon

TABLE 40
Recommendations for mitral valve surgery in nonischemic severe mitral regurgitation (MR)

Indication	Class	
1. Acute symptomatic MR in which repair is likely	I	B
2. Patients with NYHA functional class II, III or IV symptoms with normal LV function defined as ejection fraction >0.60 and end-systolic dimension <45 mm	I	B
3. Symptomatic or asymptomatic patients with mild LV dysfunction, ejection fraction 0.50 to 0.60, and end-systolic dimension 45 to 50 mm	I	C
4. Symptomatic or asymptomatic patients with moderate LV dysfunction, ejection fraction 0.30 to 0.50, and/or end-systolic dimension 50 to 55 mm	I	C
5. Asymptomatic patients with preserved LV function and atrial fibrillation (recent onset)	I/IIa*	C
6. Asymptomatic patients with preserved LV function and pulmonary hypertension (pulmonary artery systolic pressure >50 mmHg at rest and >60 mmHg with exercise)	I/IIa*	C
7. Asymptomatic patients with ejection fraction 0.50 to 0.60 and end-systolic dimension <45 mm, and asymptomatic patients with ejection fraction >0.60 and end-systolic dimension 45 to 55 mm	I/IIa*	C
8. Patients with severe LV dysfunction (ejection fraction <0.30 and/or end-systolic dimension >55 mm) in whom chordal preservation is highly likely	IIa	C
9. Asymptomatic patients with chronic MR with preserved LV function in whom mitral valve repair is highly likely	IIb	C
10. Patients with mitral valve prolapse and preserved LV function who have recurrent ventricular arrhythmias despite medical therapy	IIb	C
Contraindication		
11. Asymptomatic patients with preserved LV function in whom significant doubt about the feasibility of repair exists	III	C

**Class I Mitral repair highly likely; Class IIa Mitral replacement likely. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (9). LV Left ventricular; NYHA New York Heart Association*

leads to mitral valve regurgitation due to systolic leaflet restriction (Carpentier type IIIb). Posterior and lateral displacement are worse than pure apical displacement. Functional mitral regurgitation is always due to loss of coaptation. Annular dilation (Carpentier type I) by itself must be considerable before loss of central coaptation occurs and therefore is rarely the sole mechanism of regurgitation in these patients. There is usually echocardiographical indentified anatomic substrate for combined type I and type IIIb mitral regurgitation.

Indications for treatment and management

Preamble: While the management of structural, acute ischemic mitral regurgitation is fairly well accepted, consisting of emergent or urgent mitral valve surgery, the treatment of chronic structural and functional ischemic mitral regurgitation is much more complex and the literature offers no strict management guidelines. The recommendations that follow are therefore the result of the experience of the primary panel members.

Structural: Acute mitral regurgitation is an uncommon complication of acute myocardial infarction and the incidence has probably been significantly reduced with the widespread use of thrombolytic therapy. In the case of complete rupture of the papillary muscle, this very serious complication is accompanied by rapid, profound hemodynamic instability and only 25% of patients are expected to survive if treated nonsurgically. Partial rupture of the papillary muscle is associated with a one-month survival of 50% when treated medically and these patients develop chronic, severe mitral regurgitation.

Medical treatment: The medical management of acute severe mitral regurgitation complicating acute myocardial infarction should be aimed at hemodynamic stabilization in preparation for surgery and consists of intubation and institution of mechanical ventilation with positive end-expiratory pressure. Percutaneous institution of cardiopulmonary bypass (CPB) may be useful before transfer to the operating room in extreme cases. Hemodynamic management should be aimed at afterload reduction with intra-aortic balloon pump (IABP) counterpulsation and inotropy to maintain systemic perfusion.

Surgical treatment: The coronary artery bypass grafts should preferably be performed before mitral surgery and should be dictated by preoperative coronary angiography (147).

Total papillary muscle rupture can rarely be amenable to repair and the valve should be replaced by a prosthesis with every effort made to preserve the intact portion of the subvalvar apparatus in order to preserve LV function. Techniques to replace the ruptured portion of the subvalvar apparatus have been described and should be used.

Partial papillary muscle rupture may be addressed by reparative techniques accompanied by remodelling ring annuloplasty. After completion of the operation, competency of the valve should be tested by TEE.

Functional: Functional ischemic mitral regurgitation may present acutely or chronically. In both cases, the timing of evaluation is controversial. The most reliable technique to evaluate patients while ischemia-free, is transthoracic or TEE. Transthoracic echocardiogram is preferable in an awake patient for sedation with TEE can downgrade MR. Leaflet closure should be qualitatively assessed. The measurements should include effective regurgitant orifice area, because a regurgitant orifice area of 20 mm^2 or greater and regurgitant volume of 30 cc or greater correlates with mortality. The width between the papillary muscles must be assessed and can be evaluated by the transgastric view on TEE. Functional mitral regurgitation is a dynamic phenomenon and is highly variable with hemodynamic conditions. It may be necessary to unmask significant mitral regurgitation by exercise such as stress echocardiography aided by evaluation of oxygen consumption. Patients who demonstrate no, or mild, mitral regurgitation while ischemia-free are likely to benefit from revascularization alone (148).

The patients can be evaluated perioperatively after induction of anesthesia by volume loading or afterload manipulations and concurrent TEE but the hemodynamic alteration caused by profound cardiac anesthesia may render this technique less reliable for identifying the patients who might benefit from mitral surgery (149,150). Irrespective of these considerations, intraoperative assessment of functional mitral regurgitation should be done in all patients with remodelled ventricles by TEE, but should not be the primary determinant of mitral intervention. TEE is helpful in examining leaflet anatomy but can be misleading because of the nonphysiological conditions. TEE is also beneficial in assessment of mitral valve repair.

The preoperative assessment should include LV end-systolic volume index (LVESVI) because it is a major determination of functional mitral regurgitation. LVESVI is a marker of systolic dysfunction and prognosis (151-153). It can be measured by biplane ventriculography, echocardiography, magnetic resonance imaging or radionucleotide imaging.

The surgical management of functional ischemic mitral regurgitation is based on the mechanistic etiology of the functional regurgitation from ventricular remodelling after myocardial infarction (88,154-177) (Table 41).

If the degree of mitral regurgitation in the acute setting varies significantly with episodes of ischemia and if good target vessels are identified on the coronary angiography, it is likely that these patients will benefit from coronary artery bypass surgery alone. This therapy is effective with reversible ischemic LV dysfunction that will improve after coronary bypass surgery.

If the mitral regurgitation is grade two with a large area of reversible ischemia and nondilated remodelled ventricles, then revascularization alone may be appropriate therapy.

If the mitral regurgitation is grade two in nondilated remodelled ventricles without evidence of reversible ischemia, then corrective mitral surgery with reduction annuloplasty and revascularization may be warranted (143,150,166). These patients with mild to moderate ischemic MR may be experiencing periods of severe MR. Grade two (mild to moderate) or more mitral regurgitation in nondilated ventricles require mitral annuloplasty unless there are indications of prohibitive operative risk (143,150,166).

The recommendations are based on the findings of the Survival and Ventricular Enlargement (SAVE) trial (178) that even mild degrees of mitral regurgitation had a substantial excessive risk of cardiovascular mortality within five years after myocardial infarction. Surgery for grades one to two, or higher, MR with impaired LV function provide better survival and improved function (143,166,170,179-188). Residual mitral regurgitation of grade two or higher after surgery has been identified to be a strong predictor of poor survival (164).

If mitral insufficiency is graded at 3+ or 4+ and the patient is ischemia-free, coronary artery bypass surgery should be accompanied by corrective mitral valve surgery. Tight restrictive remodelling annuloplasty can be considered the procedure of choice but long term results may dictate mitral replacement with preservation of the subvalvar apparatus. The restrictive remodelling annuloplasty must reduce the septal-lateral (antero-posterior) dimension to at least the size of the anterior leaflet with a tight rigid or semirigid annuloplaty ring.

It has been identified that moderate to severe MR sould be considered a relative contraindication for percutaneous coronary intervention (190).

Restrictive remodelling annuloplasty may be ineffective because of ventricular dilation which displaces the papillary muscles and impairs leaflet coaptation with incomplete mitral leaflet closure. Global or regional remodelling leads to ventricular dilation and changes the normal ellipse to a more spherical shape. The remodelling results in mitral annular enlargement, papillary muscle displacement and leaflet restriction (tenting), which prevents leaflet coaptation. The residual mitral regurgitation after annuloplasty can be due to the manifestations of remodelling before annuloplasty or persistent after surgery.

There is lack of evidence to recommend mitral valve annuloplasty or replacement with chordal preservation. Recurrence of mitral regurgitation after repair is likely due to altered mitral valve leaflet coaptation. The two procedures for grade three and four functional regurgitation provide equally poor results. Additional evidence indicates that MVR may not achieve better survival. MVR can be reserved for intraoperative failures when appropriately downsized remodelling annuloplasty does not correct MR to +1 (143,164,179,188,189).

Chronic, functional ischemic mitral regurgitation (grade 3+ or 4+) should be addressed by coronary artery bypass surgery and elimination of the mitral regurgitation. The use of repair techniques (tight remodelling annuloplasty) versus replacement with preservation of the subvalvular apparatus is controversial but both techniques can be used with acceptable perioperative results (191).

Ventricular restoration surgery to treat functional mitral regurgitation with dilated remodelled ventricles has had limited evaluation but is being assessed in the RESTORE trial (192,193). The surgical therapy should address all components of the mitral apparatus and ventricle including revascularization of viable myocardium, reduction of ventricular volume and restoration of shape, realignment of papillary muscles and decrease of annular orifice size (194).

Congestive heart failure is the major cause of mortality and morbidity and is most often caused by systolic LV dysfunction. LV remodelling and dysfunction are frequently accompanied by mitral regurgitation and further deterioration of clinical status. Functional mitral regurgitation occurs despite structurally normal mitral valve leaflets and is a consequence of LV remodelling. LV dysfunction precedes LV remodelling and functional mitral regurgitation.

The global and regional remodelling leads to ventricular dilation and changes the normal elliptical shape to a more abnormal spherical shape. These geometric abnormalities result in mitral annular enlargement, papillary muscle displacement, leaflet restriction (tenting) and leaflet coaptation away from the mitral annulus plane toward the apex. The LV dilation deforms the mitral apparatus and causes functional regurgitation by systolic leaflet tethering. Ventricular sphericity causes functional mitral regurgitation by widening the LV transverse diameter, displacing the papillary muscles and disrupting leaflet coaptation. Increased LV sphericity correlates with systolic mitral leaflet tethering and incomplete mitral leaflet coaptation. Chronic postmyocardial regional remodelling and functional mitral regurgitation can result in significant pulmonary hypertension.

The infarction location and size determines the development of functional mitral regurgitation. Posterior infarction produces functional mitral regurgitation more often than anterior infarction. Anterior infarction does not enlarge or distort the mitral annulus. Posterior infarction deforms the mitral apparatus by posterior LV wall scar, asymmetric annular dilation and papillary muscle displacement by widening the basal transverse diameter of the ventricle.

TABLE 41
Recommendations for mitral valve (MV) surgery in ischemic mitral regurgitation (IMR)

	Indication	Recommendation	Class	
1.	Acute, post-MI MR with cardiogenic shock		I	B
	Complete papillary muscle rupture:	MV replacement with subvalvular preservation		
	Partial papillary muscle rupture:	MV repair/MV replacement with subvalvular preservation*	I IIa	B
2.	Unstable angina with intermittent 1+ or 2+ MR	Revascularization alone	I	B
3.	Unstable angina with persistent 3+ or 4+, 2+ MR	Revascularization + MV repair (tight annuloplasty ring)/MV replacement with subvalvular preservation*	I IIa	C
4.	Unstable angina with intermittent 2+, 3+ or 4+ MR *TTE evaluation while ischemia-free*			
	Persistent 3+ or 4+, 2+ MR:	Revascularization + MV repair (tight annuloplasty ring)/MV replacement with subvalvular preservation*	I IIa	B
	-0, or 1+ MR:	Revascularization alone		C
5.	Stable angina with 1+ MR	Revascularization alone	I	B
6.	Stable angina with 2+, 3+ or 4+ MR *TTE evaluation while ischemia-free*			
	Persistent 3+ or 4+, 2+ MR:	Revascularization + MV repair (tight annuloplasty ring)/MV replacement with subvalvular preservation	I IIa	C
	-0, or 1+ MR:	Revascularization alone	I	C
7.	Chronic, dilated ischemic cardiomyopathy with 3+ or 4+, 2+ MR	Revascularization + MV repair/MV replacement with subvalvular preservation*	I IIa	C
8.	Chronic, dilated ischemic cardiomyopathy with 3+ or 4+, 2+ MR and presence of akinetic or dyskinetic scar	Revascularization + MV repair with reduction of annular orifice size/MV replacement with subvalvular preservation* + reduction of ventricular volume and restoration of shape and realignment of papillary muscles.	I IIa	C

**Clear controversy exists between MV repair versus replacement in this population. MR 3+ or 4+ are generally accompanied with ventricular dysfunction (class 1+ to 3+ or 4+). MR 2+ is class IIa. MR 2+ requires extra clinical judgement as an indication for operative management for all indications in this table. An effective orifice area (ERO) > 0.2 cm^2, reduced left ventricular function or an enlarged left ventricular end-systolic size (ideally obtained during a preoperative transthoracic echocardiogram when the patient is neither ischemic nor under abnormal loading conditions), a dilated mitral annulus with a central jet of MR, assurance that the mitral regurgitation can be reduced or eliminated with a mitral valve repair that will not excessively prolong the CPB time argue for a mitral valve procedure in this setting. In the absence of all of these features, with a mitral valve that appears structurally normal, revascularization alone should be strongly considered. Cases that lay at either extreme should be evaluated on an individual basis. MI Myocardial infarction*

The surgical management of functional mitral regurgitation must be directed to restoring the elements of the mitral apparatus changed by LV remodelling (195). The decision-making process for mitral valve repair must be based on preoperative measurements of ventricular volume, annular size and the degree of papillary muscle displacement. The surgical interventions include revascularization to good target vessels and viable myocardium, modification of the mitral apparatus by narrowing the annulus and reducing width between the displaced papillary muscles, reduction of ventricular volume and restoration of elliptical shape from the distorted spherical shape.

The surgical procedure incorporates correction of the increased end-systolic chamber sphericity index. This includes reduction of the posterior mitral annulus and downsizing of the total annulus, and exclusion of noncontracting akinetic or dyskinetic ventricle, with an intraventricular patch. The noncontracting segments can involve septum, inferior wall and portions of lateral wall. This procedure preserves normal elliptical shape. The size of the new ventricular cavity can be optimized by the Fontan suture, intraventricular balloon and intraventricular patch. This surgical technique is superior to the conventional direct linear closure of LV free wall without exclusion of the septum.

The techniques of surgical ventricular reconstruction and mitral regurgitation management have been reported in 924 patients over 10 years, and specific mitral ventricular approach techniques in 363 patients (196). The current RESTORE trial is evaluating the techniques in a prospective study. The long term survival benefit with increased early mortality (approximately 8%) requires assessment.

In dilated remodelled ventricles with no preoperative functional mitral regurgitation, there is considered opinion that components of the mitral apparatus should be prophylactically corrected so as to prevent potential progression to functional mitral regurgitation, ie, correct the annular dimension, papillary muscle displacement, ventricular volume and sphericity. It is recommended that a prospective study be conducted to address this issue.

In the case of dilated, ischemic cardiomyopathy with 3+ or 4+ mitral regurgitation, LV volume reduction, even with mitral correction, has been less successful. On the other hand, if there is a large akinetic or dyskinetic scar, excision with endoaneurysmorrhaphy patch remodelling of the ventricle, with elimination of the mitral regurgitation, has had useful medium term results (192,193,196).

The optional prosthesis type for valve replacement in patients on chronic renal dialysis is unresolved. In 1998, the ACC and AHA continued to recommend mechanical prostheses (9). The publications since 1998 have overwhelmingly recommended bioprostheses (197-200). It was considered that patients on chronic dialysis do not generally survive long enough to experience structural valve deterioration. The two-year survival rate was only 39% for both bioprostheses and mechanical prostheses (199). Mechanical prostheses have been demonstrated to have a sixfold higher incidence of late bleeding or stroke (200).

MULTIPLE VALVE DISEASE

The literature does not provide evidence for management guidelines of multiple valve disease (201-204). The number of combined hemodynamic disturbances require individualization in management.

MIXED MITRAL AND MIXED AORTIC DISEASE

Pathophysiology

If the predominant lesion is mitral stenosis, the LV will be of normal volume while if the lesion is predominantly mitral regurgitation, the chamber will have sustained dilation. The regurgitant-dominated lesion may have a transvalvular gradient that does not represent severe mitral stenosis.

Diagnosis

Two-dimensional and Doppler echocardiography provide more accurate determination of hemodynamics than cardiac catheterization.

Indications for intervention

There are no guidelines to guide therapy; the approach is to perform surgery when the disease produces more than mild symptomatology. Aortic stenosis-dominant lesions should undergo surgery when associated with mild symptoms whereas dominant aortic regurgitation should be observed until symptomatic or if LV dysfunction develops. Percutaneous mitral balloon valvotomy is contraindicated in moderate to severe regurgitation.

COMBINED MITRAL STENOSIS AND AORTIC REGURGITATION

Pathophysiology

In most cases, severe mitral stenosis coexists with mild aortic regurgitation but aortic regurgitation may be severe. Severe mitral stenosis and aortic regurgitation produce confusing pathophysiology. The complex combination requires echocardiography and cardiac catheterization for diagnosis.

Indications for intervention

Symptoms and pulmonary hypertension are usual indications for intervention. If PMBV is feasible and successful, aortic regurgitation may be followed and replacement delayed.

COMBINED MITRAL STENOSIS AND TRICUSPID REGURGITATION

Pathophysiology

Pulmonary hypertension usually coexists with mitral stenosis and tricuspid regurgitation.

Diagnosis

Doppler echocardiography can estimate PAP in the presence of tricuspid regurgitation, as well as anatomy of both valves.

Indications for intervention

Mitral valvotomy may be performed regardless of symptom status and, if successful, tricuspid regurgitation and pulmonary hypertension usually diminish. Mitral valve surgery should be accompanied by tricuspid annuloplasty especially if right heart failure is evident. If right atrial (RA) or RV diastolic pressures are not elevated, tricuspid regurgitation is likely to resolve after MVR. The tricuspid valve must be evaluated at surgery and, if the tricuspid regurgitation is considered functional without dilation, an annuloplasty may not be necessary.

COMBINED MITRAL AND AORTIC REGURGITATION

Pathophysiology

The pathophysiological effects of mitral regurgitation and aortic regurgitation dictate different guidelines for surgery. The dominant lesion determines the approach to surgery.

Diagnosis

Two-dimensional echocardiography is required to assess the severity of aortic regurgitation and mitral regurgitation, LV size and function, LA size, pulmonary hypertension and feasibility of mitral valve repair.

Indications for intervention

Mild to moderate mitral regurgitation may occur secondary to LV dysfunction in chronic, severe aortic regurgitation (as well as stenosis). It may then improve after AVR and coexistent mitral replacement or repair may not then be indicated. If the mitral regurgitation is more than moderate, or if the mitral valve has signs of organic disease, coexistent mitral surgery is necessary.

COMBINED MITRAL AND AORTIC STENOSIS

Pathophysiology

The combined valve stenosis is usually rheumatic in origin.

Diagnosis

Two-dimensional and Doppler echocardiography are performed to assess the severity of aortic stenosis and mitral stenosis, with evaluation of mitral stenosis for mitral balloon valvotomy, and to determine ventricular size and function.

Indications for intervention

Mitral balloon valvotomy may be attempted first if aortic stenosis is mild; otherwise it is necessary to proceed with a double valve replacement.

COMBINED AORTIC STENOSIS AND MR

Pathophysiology

The disease combination may be from varied etiology, namely, rheumatic valve disease, congenital aortic stenosis and mitral valve degenerative disease, or degenerative aortic stenosis and mitral regurgitation. The latter may occur in the elderly with severe posterior annular calcification of the mitral valve. The mitral regurgitation may enhance LV ejection performance and mask systolic dysfunction of aortic stenosis. Atrial fibrillation may also compromise LV output.

Diagnosis

Two-dimensional and Doppler echocardiography are performed to determine severity of lesions and LV size, wall thickness, LA size, PAP and RV function.

Indications for intervention

Severe symptomatic aortic stenosis and mitral regurgitation with LV dysfunction or pulmonary hypertension should have

TABLE 42
Recommendation for valve replacement with a mechanical prosthesis

Indication	Class	
1. Patients with expected long lifespans	I	B
2. Patients with a mechanical prosthetic valve already in place in a different position than the valve to be replaced	I	B
3. Patients requiring warfarin therapy because of risk factors* for thromboembolism	IIa	C
4. Patients ≤65 years for aortic valve replacement and ≤70 years for mitral valve replacement	IIa	C
5. Valve replacement for thrombosed biological valve	IIb	C
Contraindication		
6. Patients in renal failure, on hemodialysis or with hypercalcemia	III	C
7. Patients who cannot or will not take warfarin therapy	III	C

**Risk factors: atrial fibrillation, severe left ventricular dysfunction, previous thromboembolism and hypercoagulable condition; Increasing the age at which patients may be considered for bioprosthetic valves is based on the major reduction in rate of structural valve deterioration after age 65 and the increased risk of bleeding in this age group. Adopted and modified from American College of Cardiology and American Heart Association Guidelines (9)*

TABLE 43
Recommendations for valve replacement with a bioprosthesis

Indication	Class	
1. Patients who cannot or will not take warfarin therapy	I	B
2. Patients ≥65 years needing aortic valve replacement who do not have risk factors for thromboembolism*	I	B
3. Patients considered to have possible compliance problem with warfarin therapy	IIa	C
4. Patients >70 years needing mitral valve replacement who do not have risk factors for thromboembolism*	IIa	C
5. Valve replacement for thrombosed mechanical valve	IIb	C
6. Patients <65 years	IIb	C
7. Patients in renal failure, on hemodialysis or with hypercalcemia	IIb	C
Contraindication		
8. Adolescent patients who are still growing	III	C

**Risk factors: atrial fibrillation, severe left ventricular dysfunction, previous thromboembolism and hypercoagulable condition; The age at which patients should be considered for bioprosthetic valves is based on the major reduction in rate of structural valve deterioration after age 65 years and increased risk of bleeding in this age group. Adopted and modified from the American College of Cardiology and American Heart Association Guidelines (9)*

combined AVR and mitral valve repair or replacement. Mild to moderate aortic stenosis with severe mitral regurgitation and LV dysfunction or pulmonary hypertension and an aortic valve mean gradient of at least 25 mmHg should have AVR with the mitral procedure. For lesser degrees of aortic disease, the surgeon must inspect the valve and decide on the need for replacement.

The choice of prosthesis is again a decision to be made by the surgeon and the patient, with full knowledge of the advantages and disadvantages of the different types available. The patient must be informed that the valve replacement is only an alternative to valve reconstruction. Bioprostheses have a limited role in MVR because of the increased evidence of structural valve deterioration compared with their use for AVR (205-225). Bioprostheses are indicated in patients greater than 70 years of age and for those with comorbidity and anticipated reduced life expectancy. The actual freedom from structural valve deterioration for patients older than 70 years of age at 15 years with bioprostheses is 93% while actuarial freedom is 80% (226-228). In the the 61- to 70-year age group, these rates are 69% and 26%, respectively. Mechanical prostheses are indicated for patients 70 years of age or younger, even though there is significant valve-related morbidity (206,210,213,216-218,220,223,229-241). The linearized rate of major thromboembolism, including thrombosis, ranges between 1.5% to 2.5% per patient-year and hemorrhage rates range from 1.5% to 2.0 % per patient-year (237,238) (Tables 42 and 43).

The outcomes 15 years after valve replacement with a mechanical versus a bioprosthetic valve have been reported by the Veterans Affairs randomized trial (216). All-cause mortality was not different after MVR with mechanical prostheses versus bioprostheses. Structural valve deterioration was greater with bioprostheses for MVR in all age groups but occurred at a much higher rate in those aged less than 65 years. Thromboembolism rates were similar in the two valve prostheses, but bleeding was more common with the mechanical prostheses.

The Edinburgh randomized trial reported in 2003 results to 20 years (217). The prosthesis type did not influence survival, thromboembolism or endocarditis. Major bleeding was more common with mechanical prosthesis. Assessing mortality and reoperation, survival with original prosthesis became different at eight to 10 years for MVR and 12 to14 years for AVR (217).

The choice of prostheses for multiple replacement surgery must be based on the type of concurrent mitral valve surgery to be performed (201-203) (Tables 42 and 43).

ABLATION PROCEDURES

The role of atrial fibrillation ablation surgical techniques in concert with mitral valve surgery is in evolution (242-246).

Atrial fibrillation as a residual following successful mitral reconstruction or MVR with a bioprosthesis leaves the patient in need of chronic anticoagulation and at risk of embolic and hemorrhagic strokes (247).

The surgical management for atrial fibrillation was pioneered in the early 1990s and the Cox-Maze III procedure has evolved as the gold standard. The success rate for surgical ablation in the control of lone atrial fibrillation is approximately 98% (248).

The success rate for control of atrial fibrillation with the Maze III procedure accompanying mitral valve repair or replacement ranges between 75% and 90%. The overall aim is to prevent re-entrant atrial fibrillation and provide better atrial transport function combined with symptomatic relief of palpitations. The Cox-Maze procedures involve complexity of incisions and suture reconstruction with use of cryosurgery. The complexity of the procedure and the potential morbidity and mortality have resulted in limited acceptance by cardiac surgeons worldwide. For this reason, there are multiple procedures and technologies emerging to facilitate acceptance of concomitant procedures to control atrial fibrillation.

The pathogenesis and mechanisms of atrial fibrillation dictate the proposals for management (242,249-251). Ablation procedures are indicated for paroxysmal and chronic atrial fibrillation. Paroxysmal atrial fibrillation is initiated by irritable cells in the pulmonary veins at the junction of the pulmonary vein endothelium and the LA endocardium. Chronic atrial fibrillation is due to multiple macro re-entrant circuits throughout the atria. The Cox-Maze III procedure is designed to control the macro re-entrant circuits by pulmonary vein isolation (left and right), LA appendage isolation and obliteration, connections between pulmonary vein isolation, as well as to the LA appendage, mitral annulus and intra-atrial septum, and the isthmus of the inferior vena cava and coronary sinus, to ablate coronary sinus conduction and the risk of residual atrial flutter (242-256). The Cox-Maze procedure also incorporates RA connections for completion of the procedure. The current conduct of the Cox-Maze III procedure can incorporate surgical incisions and cryosurgery lesions (242). There are several reports of modifications of the Cox-Maze III procedure incorporating anatomic alterations and accommodating alternative technologies (257-262).

The evolving technologies for atrial fibrillation ablation incorporate radiofrequency, cryotherapy, microwave, laser and ultrasound. The efforts at percutaneous catheter pulmonary vein isolation and ablation have essentially been abandoned because of the extensive length of procedures and the high incidence of pulmonary vein stenosis (245). The recognized alternative management has been atrioventricular nodal ablation and permanent pacemaker to control ventricular rate, but anticoagulation is still required because of persistent atrial fibrillation.

The operative procedure is conducted with radiofrequency. This includes evaluation of ablation procedures from an epicardial as well as an endocardial approach, either partially or completely. Cryosurgery and radiofrequency are used for the epicardial approach. The epicardial approach may be advanced with minimally invasive techniques either for management of lone atrial fibrillation or chronic atrial fibrillation concomitant with moderate or severe mitral regurgitation.

The developing technologies attempt to duplicate conventional rhythm surgery where atrial tissue is multiply incised and then sutured to provide contiguous lesions to anatomic re-entrant circuits. The newer technologies have been developed to create transmural lesions during cardiac surgery; a potential limitation is the ability to perform and confirm that lesions are transmural.

Radiofrequency ablation: This is a safe and established method in the treatment of a variety of supraventricular arrhythmias such as AV nodal re-entry and atrial flutter (263-276). Radiofrequency may be unipolar or bipolar. Lesions are formed by local tissue heating. Radiofrequency is unmodulated alternating current delivered in the range of 0.5 to 1.0 MHz between two electrodes, one located on the endocardial surface and the other on the skin. The mechanism of heat generation with radiofrequency is by resistive or ohmic heating. The highest current density is reached at the point where the tissue is in contact with the active electrode. Heating produces homogeneous lesions that measure a few millimetres in diameter and depth. The true resistive heating occurs around 1 mm deep into the tissue and the remainder of ablation occurs from conductive heating from area of resistive heating. The volume of linear lesions is limited by the electrode surface area, energy delivered and contact of the electrode with the tissue. Energy delivery has to be sufficiently high for effective heating but not high enough for coagulum formation.

Unipolar ablation relies on grounding pads to act as the other pole and is the simplest way to apply the energy. The unipolar method is the most controlled but slowest and most inefficient of the radiofrequency modalities. It has been demonstrated that reliable and effective ablation is performed at 70°C for 60 s. The goal temperature should never be set at more than 95°C to avoid potential tissue disruption.

Biopolar radiofrequency is another radiofrequency modality that has the ability to make very fast and dicrete lesions. The modality simply relies on having a pole on each side of the tissue to be ablated. This focuses all of the energy between the two poles and lesions can be made in less than 10 s. The biopolar products have impedance sensors that detect transmural ablation, but repeated ablations may be necessary for reliability. These lesions are predominantly created from the epicardium, and therefore is effective only if tissue is opposed. There is limited flexibility with the biopolar device and epicardial fat is a limiting factor.

Cooled radiofrequency devices are complex systems that are important for isthmus ablation to prevent postablation atrial flutter (277-280). Cooled radiofrequency ablation was introduced to allow higher energy output, avoiding coagulum formation. It therefore provides wider and deeper lesions.

The cooling effect on the surface of the tissue (endocardium or epicardium) actually drives the focus (hottest point) of energy deeper into the tissue, providing a faster and deeper ablation.

Cryoablation: This has been used in cardiac surgery as a concomitant procedure for ablation of tachycardias for more than a decade (281). Cryoablation with the extensive clinical use has now been used to complete an entire Maze procedure. Cryoablation has an excellent clinical safety record, though its use in atrial fibrillation surgery has been reserved for creating spot lesions over the tricuspid and mitral valve annuli.The standard features of the procedure are rapid freezing, and slow thawing with repeated freeze and thaw cycles. The coldest temperature (the prime determinant of cell death) may range between —50°C and —150°C and the application time can range between 0.5 and 5 min, dependent on the area of application. The traditional systems are nitrous-based but the newer argon and helium-based systems allow for much colder temperatures, which may limit the ablation time. The role of cryoablation will continue to be endocardial even with new variable length and flexible probes.

Laser ablation: The laser lesion formation is thermal through photon absorption at the surface with deeper myocardial sites heated through passive conduction. The primary enabling technology for laser ablation is the fiberoptic delivery devices rather than the laser itself. The delivery device has a diffusing

TABLE 44
Indications for concomitant Maze for mitral valve surgery

Indication	Class	
1. Atrial fibrillation lasting >1 year	IIb	C
2. Symptomatic refractory atrial fibrillation in young patients	IIb	C
3. Mitral valve repair (simple) with chronic atrial fibrillation	IIb	C
4. Valvular heart disease with atrial fibrillation performed with valve repair or bioprosthesis mitral replacement	IIb	C
5. Mitral repair or replacement (bioprosthesis) with embolic stroke on anticoagulants	IIb	C
6. Selected cases of left ventricular dysfunction with chronic atrial fibrillation	IIb	C

tip that contains silicon particles which allows the laser to be emitted perpendicular to the fiber direction. The device creates a unidirectional linear ablation of 2 cm to 5 cm with a flexible configuration. The mechanism is wavelength dependent by creating harmonic oscillation in water molecules with resulting kinetic energy and heat generation. The wavelength chosen for good penetration is a 980 nm diode laser. This wavelength ablates tissue with absorption of actual laser energy as deep as 4 mm into the tissue and further ablation by conductive heating mechanisms. The lesion times are for 36 s utilizing 5W/cm but ablation can not be longer than 5 cm. Laser ablation can be applied to the epicardium, as well as endocardium because transmural lesions pass even through epicardial fat.

Microwave ablation: This is considered to cause effective and controlled heating of large tissue volumes without causing charring of either the endocardial or epicardial surfaces (282-284). The electromagnetic microwaves occur at 2.45 GHz to generate frictional heating by induction of dielectric ionic movements. The method spares the endocardial surface, and local tissue necrosis and scars can be penetrated. The microwave device can provide a range of 40 to 45 watts of power for 20 to 30 s, generating a consistent 3 to 6 mm lesion depth sufficient to produce transmural ablation. The deeper penetration with microwave energy has more potential to be successful at epicardial ablation. Microwave also deals far better than radiofrequency through fat, which is a significant barrier with radiofrequency energy.

Ultrasound ablation: This technology uses an ultrasound transducer to deliver mechanical pressure waves at high frequency. The tissue destruction is thermal and lesion depth corresponds to vibrational frequency. The ultrasound wave is emitted from the transducer and resulting wave travels through tissue causing compression, refraction and particle movement, resulting in kinetic energy and heat. Ultrasound can be applied in either a high intensity focused manner or a nonfocused manner. There is the potential that ultrasound may both ablate and image, thus providing confirmation that the lesion is transmural.

The new, less invasive ablation techniques must demonstrate consistency and reproducibility. They must be shown to be safe, reliable and effective with no added morbidity and mortality, and should be satisfactory for ablation of paroxysmal, persistent or intermittent chronic atrial fibrillation. The technologies should be optimal for either nonbeating or beating hearts, full sternotomy or less invasive thoracotomy. Ablation procedures should be performed at the time of valvular surgery although they can be performed as stand alone procedures in nonvalvular disease. (Table 44).

Special surgical considerations

Mitral regurgitation with posterior annular calcification is best managed by excision of the bar of calcium and reconstruction of the mitral annulus with the free autologous pericardium (285-287). The valve is repaired or replaced depending on the status of the anterior mitral leaflet. The same technique is used for atrioventricular groove repair.

Severe mitral regurgitation with severe LV dysfunction (ejection fraction less than 25%) and incomplete knowledge of the etiology of regurgitation is best managed by mitral replacement with preservation of the posterior leaflet. The results of mitral valve repair in ischemic mitral regurgitation have been considered suboptimal and disappointing, but these opinions are controversial.

The mechanism of mitral regurgitation in ischemic disease is often extremely difficult to precisely determine preoperatively and intraoperatively. The mitral annulus may not be dilated on echocardiographic assessment. Annuloplasty alone may be adequate over time for control of ischemic mitral regurgitation in some patients. Large prostheses may adversely affect LV function and outcome.

The management of concomitant degenerative and ischemic mitral regurgitation is best managed with techniques for both abnormalities and recurrence may not be different than for pure degenerative disease.

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SECTION V: TRICUSPID VALVE DISEASE IN THE ADOLESCENT AND ADULT

Etiology and physiopathology

Tricuspid valve dysfunction can occur in patients with structurally normal valves or secondary to organic disease. The majority of patients have tricuspid regurgitation resulting from one or more of the following:

1. An elevation of RV systolic pressures, usually secondary to pulmonary hypertension due to organic or functional left heart disease (eg, MS). RV outflow obstruction (eg, pulmonary stenosis, Tetralogy of Fallot) can also induce tricuspid regurgitation;
2. An elevation of RV diastolic pressures as seen with dilated cardiomyopathy;
3. RV enlargement and tricuspid annular dilation.

Many patients without cardiac disease have some degree of physiological tricuspid regurgitation that is not clinically significant (1,2).

Organic tricuspid lesions cause tricuspid regurgitation, stenosis or more often a combination of both. Tricuspid regurgitation can be due to rheumatic valvulopathy, infectious endocarditis, Carcinoid syndrome, rheumatoid arthritis, radiation therapy, trauma, Marfan's disease, congenital anomalies (Ebstein's anomaly, atrioventricular septal defect), systemic lupus erythematosis, antiphospholipid syndrome and anorectic drugs. Stenosis can also be associated with rheumatic valve disease, congenital anomalies in addition to Fabry's disease, Whipple's disease, previous methysergide therapy and secondary to RA masses. Tricuspid stenosis is not caused by infective endocarditis alone and very rarely by Carcinoid syndrome. The RA mass can mimic tricuspid stenosis but does not cause it.

Diagnosis

Echocardiography is the diagnostic modality of choice for the assessment of tricuspid valve structure and function including leaflet mobility, annular size, chordal or papillary muscle integrity, pressure gradients, and the severity of regurgitation. Other cardiac abnormalities that influence valve function can also be identified, ie, pulmonary hypertension and RV function. Systolic PAP greater than 55 mmHg may cause tricuspid regurgitation in patients with anatomically normal tricuspid valves, whereas tricuspid regurgitation occurring with systolic PAP less than 40 mmHg is more likely to reflect a structural abnormality of the valve apparatus.

The severity of tricuspid regurgitation is determined by colour flow Doppler and expressed as the area of the regurgitant jet (moderate tricuspid regurgitation greater than 4 cm^2) or as a ratio of the area of the regurgitant jet to the RA area (where a ratio of one to three is mild, a ratio of two to three is moderate, and a ratio of more than two to three is severe). Quantification of tricuspid regurgitation is, however, open to criticism because the dimension of the regurgitant jet is influenced by many factors including echogenicity of the patient, the hemodynamic state and the direction of the regurgitant jet (3,4).

Intraoperative TEE evaluation of tricuspid valve function provides useful information before and after repair of the tricuspid valve (5). The induction of anesthesia may decrease regurgitation with reduced systemic vascular resistance and LV and atrial pressures, which result in a decrease in PAP and RV afterload. To adequately evaluate the tricuspid valve pre- and postoperatively, the systemic arterial pressure must be raised to normal level (ie, adequate preload and afterload) for age.

Indications for surgical management

Tricuspid regurgitation: The management of tricuspid regurgitation is determined by clinical status of the patient and etiology of the valve abnormality. Patients with severe tricuspid regurgitation of any cause have poor long term outcome due to RV dysfunction, atrial arrhythmia or complications of chronic systemic venous congestion. Diuretics are the mainstay of initial medical treatment.

The assessment of tricuspid regurgitation should include an evaluation of the jet area (not as a proportion of the RA area), the width of the jet, flow acceleration within the right ventricle, density and shape of the continuous wave signal, hepatic vein or inferior vena cava flow, and size and activity of the right ventricle.

Transthoracic or intraoperative TEE using two-dimensional and Doppler imaging better define the mechanisms responsible for regurgitation. It is then possible to tailor valve repair to correct the anomaly and optimize results (3,5).

Ebstein's anomaly: The surgical repair of Ebstein's anomaly includes the correction of tricuspid regurgitation, control of intracardiac shunts and improvement of RV function. Accessory conduction pathways leading to re-entry arrhythmias are mapped pre- or intraoperatively and pathways are ablated either during surgery or in the catheterization laboratory before surgery. In patients with atrial flutter, cyroablation of the inferior vena cava-right atrial junction may ablate the arrhythmia (6). With atrial fibrillation, a right-sided Maze procedure has been proposed (7). The atrial septal defect associated with Ebstein's anomaly is usually closed to eliminate desaturation due to right to left shunting and also to eradicate the risk of paradoxical embolism.

The tricuspid valve can be repaired if the anterior leaflet can be mobilized and if it is not obstructing the RV inflow. The valve can be repaired in a number of ways (8-10); however, a comparative study has never been performed to identify the optimal technique. Plication of the atrialized portion of the RV remains controversial.

In patients with inadequate RV function, a bidirectional cavopulmonary shunt is recommended in addition to the intracardiac repair, provided that the pulmonary vascular resistance is normal (11-13). With extreme RV dysfunction, the atrial septum may be also fenestrated (11). The bidirectional cavopulmonary shunt reduces RV preload, reduces RV failure and potentially improves residual postoperative tricuspid regurgitation. It appears to improve the repair rate, survival and freedom from reoperation (11-13).

Long term survival (8) and NYHA functional class improve after repair of Ebstein's anomaly (8-14). Supraventricular arrhythmia appears to be better tolerated and responds more readily to pharmacological treatment (15). In the presence of a right to left shunt, a more aggressive surgical approach should be considered before the onset of atrial arrhythmias, to avoid

TABLE 45
Recommendations for surgery in the adolescent or adult with Ebstein's anomaly

Indication	Class	
1. Deteriorating exercise capacity	I	B
2. Progressive cyanosis with arterial saturations <90% at rest	I	B
3. Severe tricuspid regurgitation with increase in symptoms (NYHA functional class III or IV) with or without progressive cardiac enlargement with a cardiothoracic ratio >60%	I	B
4. Paradoxical embolism	I	B
5. Atrial arrhythmia	IIa	C
6. NYHA functional class II with valve that has a high probability of being repaired with or without deteriorating exercise tolerance	IIa	C
7. Asymptomatic with progressive cardiomegaly (cardiothoracic ratio >60%)	IIb	C

NYHA New York Heart Association

systemic embolization with associated morbidity and mortality (Table 45).

Valve replacement is only performed in the context of a failed repair or a population subset with more dysmorphic features not amenable to repair (8-14).

Tricuspid regurgitation associated with left heart lesions: Tricuspid valve interventions are most frequently performed for tricuspid regurgitation secondary to mitral valve disease. Tricuspid valve procedures at the time of mitral surgery have been the subject of debate. Tricuspid regurgitation decreases to varying degrees with a decrease in pulmonary hypertension and improvement in RV function following correction of a mitral lesion. The resolution of severe tricuspid regurgitation in this context cannot always be accurately predicted and can depend on several factors including the following:

1. Quality of the left-sided repair or replacement and, therefore, the degree of resolution of the pulmonary hypertension. The degree of residual systolic and diastolic LV dysfunction can also influence tricuspid patency.
2. Persistence of organic tricuspid regurgitation. Functional tricuspid regurgitation will decrease by approximately one-half with postoperative decrease in pulmonary hypertension (16).
3. Severe, chronic tricuspid regurgitation and RV dilation are less likely to regress following intervention at the level of the mitral valve (16-18).

The outcome of patients with functional tricuspid regurgitation that was not addressed during repair of left-sided valvulopathy varies between studies because of differences in patient selection and criteria for defining the severity of tricuspid regurgitation, and inconsistent use of intraoperative assessment of functional and anatomical abnormalities (16-18).

Most authors agree, however, that surgical treatment of severe tricuspid regurgitation is necessary for good long term results because regression of severe tricuspid regurgitation following mitral valve procedures cannot be relied on. Up to 35% of patients with severe functional tricuspid regurgitation not addressed at initial mitral valve surgery must undergo reoperation to correct tricuspid incompetence (18-21). In addition, reoperations for residual tricuspid regurgitation have a high mortality rate, ranging between 14% and 27% (22-24).

The operative risk for an isolated mitral procedure in patients with functional tricuspid regurgitation is reported to be less than that for a combined mitral and tricuspid operation (25,26). Pulmonary hypertension, RV dysfunction and complications of chronic systemic venous hypertension are responsible for poorer early and late results of the combined procedures (and not the additional tricuspid intervention).

Moderate tricuspid regurgitation repaired at the time of mitral intervention has an unclear prognosis (16,25); however, many authors recommend tricuspid valve repair or annuloplasty in these patients because it is safe and can help prevent the progression of the tricuspid regurgitation (27,28).

Other tricuspid lesions: Management of tricuspid regurgitation due to organic disease must be tailored to the disease process. The repair should correct anomalies of the different components of the valve (18). Traumatic chordal rupture or flail leaflets can benefit from chordal reconstruction (29) including the implantation of polytetrafluoropropylene chordae (30). Successful repair is possible in endocarditis (31,32). The valve can be converted into a bileaflet valve with resection of vegetations and the infected valve leaflets. The entire valve may be resected (33) but, preferably, the valve is repaired with standard techniques or with the addition of a patch of glutaraldehyde-treated autologous pericardium (34). If the valve is extensively involved with endocarditis, it can be resected and replaced with a mitral homograft (35,36).

Tricuspid stenosis is extremely rare. Balloon valvotomy is preferred to surgery in tricuspid stenosis (37,38).

In cases of severe mitral stenosis, after successful mitral percutaneous balloon valvotomy, both pulmonary hypertension and tricuspid regurgitation are reduced. However, long term information is not available.

Choice of repair technique: Annular dilation is the most frequent cause of tricuspid regurgitation. It can be addressed by annuloplasty with a prosthetic ring (eg, Carpentier, Duran and Cosgrove rings), prosthetic bands or without a synthetic ring (eg, De Vega and Kay-Boyd annuloplasties). In the presence of long standing severe tricuspid regurgitation, especially with tricuspid valve organic lesions and persistent pulmonary hypertension, the flexible ring provided better long term durability compared with annuloplasty performed without a synthetic ring (39-41). All of these techniques, however, were equally efficient for moderate tricuspid regurgitation due to isolated tricuspid dilation (39-41).

Choice of prosthesis: The best type of prosthesis for tricuspid replacement is a topic of ongoing debate. Porcine and bovine pericardial bioprostheses tend to be favoured due to their low rate of valve thrombosis, infrequent embolic episodes and because long term anticoagulation is not required. Porcine bioprostheses appear to be more durable in the tricuspid position compared with the mitral position, even in children. Freedom from reoperation of 80% at 10 and 15 years has been reported (42) (Table 46).

TABLE 46
Recommendation for surgical correction of tricuspid regurgitation (TR)

Indication	Class	
1. Tricuspid repair or replacement for severe primary or secondary TR, in symptomatic patients not responding to medical treatment	I	B
2. Tricuspid repair or replacement for severe TR in patients requiring mitral valve surgery, particularly in the presence of pulmonary hypertension (mean pulmonary artery pressure >50 mmHg) or right ventricular dilation and dysfunction	I	B
3. Tricuspid repair for moderate functional TR, secondary to left-heart lesion at the time of mitral valve surgery	IIa	C
Contraindication		
4. Isolated valve replacement or repair for TR, in an asymptomatic patient with normal right ventricular function	III	C

More recent reports comparing the long term results of bioprostheses and mechanical prostheses in the tricuspid position reveal no clear superiority of either (22-24,43). The new generation of bileaflet mechanical prostheses appear to offer better performance than older generations (22,43). Patients with multiple valve disease and accompanying cardiac dysfunction have limited survival rates of 31% to 37% at 15 years (22-24,43). Bioprostheses, with limited durability, are a good alternative in this patient population. In young patients with isolated tricuspid valve disease or already on an anticoagulation regime, mechanical prostheses can be considered. Mitral allografts can be used for tricuspid valve replacement (35).

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SECTION VI: CONGENITAL VALVE DISEASE

The predominant etiology of valvular disease in children, adolescents and young adults is congenital (1). In the evaluation of valvular disease in children, the severity of obstruction is reported as the peak-to-peak systolic gradient at cardiac catheterization or the maximum instantaneous gradient by Doppler echocardiography. Reporting by valve area is not used in children. The standard of reporting is peak-ventricular to peak-great vessel pressure gradients for semilunar valves and mean pressure gradients for atrioventricular valves. The peak gradient measured by Doppler (maximum instantaneous velocity) is higher than the peak-to-peak gradient measured at catheterization. Mean Doppler gradient is used more and more to try to correlate better with catheterization gradient. The ventricular end-systolic or end-diastolic diameters or volumes used for assessment of valvular regurgitation are often corrected for body surface area.

Valvular disease is often part of complex congenital cardiac anomalies such as tricuspid stenosis in children with pulmonary atresia and intact ventricular septum, or aortic stenosis from aortic valve atresia as part of the hypoplastic left heart syndrome. The management of complex anomalies with multiple valve involvement is beyond the scope of the consensus guidelines (2,3).

The management of the neonate, infant and young child differs significantly from management of the adolescent and young adult (4,5). Because of the rapid growth of the infant patient, closer follow-up has to be done, especially in the first year of life. Failure to thrive has to be recognized as a sign of heart failure.

Critical neonatal aortic stenosis (less than 28 days)

Etiology: Critical neonatal aortic stenosis is present in newborns with aortic stenosis if symptomatic. The pathological lesion is unicuspid or bicuspid aortic valve with commissural fusion. Often the valve is thickened, dysplastic or myxomatous.
Diagnosis: Echocardiographic evidence of dysplastic obstructive aortic valve is diagnostic. Infants with depressed LV function and critical aortic stenosis may have small transaortic gradients (6). Neonates may be dependent on a patent ductus arteriosus for systemic perfusion.
Pathophysiology: Aortic stenosis in the infant patient has the same pathophysiology as in the adult, except that because of rapid patient growth, the obstruction can progress rapidly with increase of LV hypertrophy (7). In some cases, fibroelastosis of the endocardium can be seen on echocardiogram.
Natural history: Neonates with critical aortic stenosis and ductus dependant systemic blood flow will develop cardiogenic shock over a period of a few hours as the ductus becomes progressively restrictive by the second or third day of life (8-11). Older infants with critical aortic stenosis and LV dysfunction progress to systemic hypoperfusion, acidosis and death.
Indications for intervention: Intervention is indicated with signs of LV failure. The treatment options are percutaneous balloon valvotomy and, if unavailable, open aortic valvuloplasty is a reasonable alternative (12-17).
Special considerations: The spectrum of the hypoplastic left heart syndrome (aortic hypoplasia, mitral stenosis and small left ventricle) overlaps with critical neonatal aortic stenosis. These infants may require a univentricular approach. (Table 47). Survival may be improved by more appropriate selection of repair pathways. Morphological and functional factors can be used to predict the optimal pathway for survival benefit in neonates with critical left ventricular outflow obstruction (18). The survival with either Norwood procedure pathway or biventricular repair can be predicted as to optimal procedure for the individual neonate in the presence of critical left ventricular outflow obstruction (18).

Noncritical neonatal and pediatric aortic stenosis

Etiology: The congenital anomaly is a unicuspid or bicuspid, often thickened, aortic valve with fusion of one or more commissures.
Diagnosis: Echocardiographic evidence of a dysplastic obstructive valve.
Natural history: The Natural History of Congenital Heart Defects study (10) reported that one-third of children over five years of age have an increase of the transaortic gradient, while patients over 12 years of age have very small increases in gradients. Those with initial peak LV-to-peak aortic pressure gradients less than 25 mmHg have less than 20% chance of intervention over 20 years. In those with an initial peak gradient greater than 50 mmHg, the occurrence of arrhythmia, sudden death and other cardiovascular events was 1.2% per year. The sudden death rate was 0.3% per year (19).
Indications for intervention: Children and young adults with LV repolarization or ischemic anomalies at rest or with exercise, or with Doppler gradients greater than 70 to 80 mmHg (peak velocity greater than 4.2 m/s) with mean gradient greater than 40 mmHg (shown to correlate with a catheterization gradient of greater than 50 mmHg) should have a cardiac catheterization and possible balloon valvotomy. Percutaneous balloon valvotomy is effective treatment (11). When balloon aortic valvotomy is ineffective or significant aortic regurgitation is present, surgical repair or AVR may be necessary. Surgical valvotomy is a reasonable alternative if skilled interventional cardiologists are not available (20) (Table 48).

Aortic regurgitation

Etiology: Aortic regurgitation is an uncommon isolated congenital lesion. It may occasionally be found in adolescents and young adults with a bicuspid aortic valve, discrete subaortic obstruction or prolapse of one aortic cusp into a ventricular septal defect. Aortic regurgitation may occur following either balloon valvotomy or surgical valvuloplasty, after attempts to relieve aortic stenosis. Aortic regurgitation and aortic root dilation may occur following complete repair of pulmonary atresia and ventricular septal defect or Tetralogy of Fallot (21).
Pathophysiology: Similar to aortic regurgitation in adults, section III.
Indications for intervention: Surgical indications for isolated aortic regurgitation or mixed aortic stenosis and aortic regurgitation are similar to adults, namely, symptoms, LV dysfunction, or very increased LV end-diastolic or end-systolic dimensions (indexed to body surface area to account for variations in body size). Recent data in adults suggest that an ejection fraction less than 55% is associated with higher mortality postoperatively (22). To preserve long term cardiac function in children, even a lower threshold might have to be used. Exercise testing should be done periodically in these patients and decreasing exercise tolerance should be regarded as an indication for valve replacement.

TABLE 47
Recommendations for aortic balloon valvotomy in neonates

Indication	Class	
1. Ductal-dependent critical aortic stenosis	I	B
2. Signs of congestive heart failure (dyspnea, tachycardia, tachypnea, low output)	I	B
3. Dilated and poorly contractile left ventricle	I	B
4. New-onset ischemic or repolarization changes on electrocardiogram at rest or with exercise (ST depression, T-wave inversion over left precordium) with a gradient >50 mmHg	I	B
Contraindication		
5. Catheterization gradient <60 mmHg without symptoms or electrocardiogram changes	III	C

TABLE 48
Recommendations for aortic balloon valvotomy in infants, children and adolescents

Indication	Class	
1. Symptoms of angina, syncope and dyspnea on exertion, with catheterization peak gradient ≥50 mmHg*	I	B
2 Catheterization peak gradient >70 mmHg	I	B
3 New-onset ischemic or repolarization changes on ECG at rest or with exercise (ST depression, T-wave inversion over left precordium) with a gradient >50 mmHg*	I	C
4 Catheterization peak gradient >50 mmHg if patient wants to play competitive sports or desires to become pregnant	IIa	C
5 Asymptomatic patient with catheterization gradient >50 mmHg for older children and >60 mmHg in infants	IIb	C
Contraindication		
6 Catheterization gradient <50 mmHg without symptoms or ECG changes	III	C

**If gradient <50 mmHg, other causes of symptoms should be explored. Adolescents and young adults almost invariably have normal or increased cardiac output. If cardiac index is less than 2 L/min/m², lower gradients should be used. ECG Electrocardiogram*

TABLE 49
Recommendations for aortic valve surgery (replacement with mechanical valve, homograft or pulmonary autograft) in children and adolescents with chronic aortic regurgitation

Indication	Class	
1. Onset of symptoms	I	B
2. Asymptomatic patients with left ventricular dysfunction (ejection fraction <0.55) on serial studies 1 to 3 months apart	I	C
3. Asymptomatic patients with progressive left ventricular enlargement (end-diastolic dimension >4 SD above normal)	I	C
4. Moderate aortic stenosis (gradient >40 mmHg) (peak-to-peak gradient at cardiac catheterization)	IIb	C
5. Onset of ischemic or repolarization abnormalities (ST depression, T-wave inversion) over left precordium at rest	IIb	C

Natural history: Several studies document the natural history of aortic regurgitation. It is apparent that regurgitation begets regurgitation and aortic insufficiency is a progressive disease. Nevertheless, the protracted clinical course of chronic aortic regurgitation is well documented (4,22). The asymptomatic state without serious hemodynamic compromise may last for many years. Unfortunately, the late appearance of clinical symptomatology creates a therapeutic dilemma with respect to the timing of surgical treatment (Table 49).

Choice of prosthesis for AVR in children, adolescents or young adults

The durability of the pulmonary autograft and its growth potential has been substantiated, making this the preferable surgical option of AVR in the growing child (23-27). In general, homografts are contraindicated in children because of early degeneration. Bioprostheses are also not indicated in pediatric and young adult patients because of a high structural deterioration rate at five to 10 years (28). In addition, mechanical prostheses can have a high reoperative rate, usually secondary to nonstructural dysfunction due to subvalvular pannus and hemolysis from paravalvular leak (29). Valve regurgitation following balloon aortic valvotomy, as a late complication, is managed by valve repair or replacement with an autograft (Table 50).

TABLE 50
Management of valve regurgitation following balloon aortic valvotomy as a late complication

Indication	Prosthesis	Class	
1. Sex, specifically female	Autograft	I	B
2. Actively growing infant or child	Autograft	IIa	B
3. Competitive athlete	Autograft	IIa	C
4. Active endocarditis	Allograft	I	B
5. Pulmonary autograft contraindicated (connective tissue disorders, unusable pulmonary valve)	Mechanical Prosthesis/Allograft	I	C

Mitral stenosis

Etiology: In developed countries, mitral stenosis, like mitral regurgitation, is the result of a wide spectrum of morphological abnormalities often coexisting with one another (small

TABLE 51
Recommendations for mitral valve surgery in children with congenital mitral stenosis (MS)

Indication	Class	
1. Intractable symptoms, New York Heart Association (NYHA) class III or IV (small children) despite maximal medical treatment	I	B
2. Severe growth failure despite maximal medical treatment	I	B
3. Symptomatic NYHA class III or IV (older children)	I	B
4. Mildly symptomatic NYHA class II with severe MS and pulmonary hypertension (older children)	IIB	C

TABLE 52
Recommendations for mitral valve surgery in the adolescents or young adults with congenital mitral stenosis

Indication	Class	
1. Symptomatic patients (NYHA functional class III or IV) and mean mitral valve gradient >10 mmHg on Doppler echocardiography	I	B
2. Mildly symptomatic patients (NYHA functional class II) and mean mitral valve gradient >10 mmHg on Doppler echocardiographic study	IIa	C
3. Systolic pulmonary artery pressure 50 to 60 mmHg with a mean mitral valve gradient 10 mmHg	IIa	C
4. New-onset atrial fibrillation or multiple systemic emboli while receiving adequate anticoagulation	IIb	C

NYHA New York Heart Association

annulus, absence of one or both commissures, short chordae, thickened immobile leaflets, double orifice mitral valve, hypertrophied or single papillary muscles, etc) (30). Supravalve mitral ring is isolated in 50% or associated with other mitral anomalies. Some cases will be in the spectrum of LV hypoplasia and should be considered beyond the scope of the consensus guidelines.

Diagnosis: Echocardiography is the diagnostic tool of choice to evaluate the morphology of the valve. Due to the frequent association of atrial septal defect and mitral stenosis, transmitral gradient should not be the only criteria used to define the degree of stenosis (31). The evaluation should include repeated measurements of LA size, resting mean and peak gradients (greater than 10 mmHg), and direct or indirect assessment of PAP. Cardiac catheterization should be reserved for when there is concern about pulmonary hypertension.

Pathophysiology: Mitral stenosis causes obstruction of LV inflow.

Natural history: Isolated congenital mitral stenosis is often severe and produces symptoms and death, if untreated, during the first four to five years of life (32). In a large series of 85 patients published in 1994 (5), 36% of patients were severely symptomatic, requiring intervention within the first two years of life. However, many infants with congenital mitral stenosis have mild stenosis that does not progress and responds favourably to medical management (33).

Indications for intervention: Surgical intervention may be necessary in severe cases. Medical management is only needed to treat complications such as endocarditis, pulmonary infections and atrial fibrillation. The surgical management of congenital mitral stenosis has improved because of TEE. Balloon valvotomy of congenital mitral stenosis is a difficult and dangerous procedure, only for experienced interventional cardiologists. Balloon valvotomy may be successful in some specific lesions such as fused commissures in rheumatic disease. Infants with severe mitral stenosis still represent an enormous challenge with a two-year mortality rate approaching 40%, regardless of treatment modality (14,31) (Tables 51 and 52).

Mitral regurgitation

Etiology: Congenital mitral regurgitation as an isolated lesion is an uncommon valvular entity characterized by a wide spectrum of morphological abnormalities (annulus, leaflets, chordae and papillary muscles) (30). The detailed functional classification of congenital mitral valve anomalies causing mitral regurgitation according to Carpentier (34) are: Type I — mitral valve incompetence with normal LM-annular dilation, cleft leaflet and leaflet defect; Type II — leaflet prolapse-chordal elongation, papillary muscle elongation and absence of chordae tendeniae; and Type III — restricted LM with normal papillary muscles due to commissure papillary muscle fusion, short chordae, with abnormal papillary muscle and parachute mitral valve, hammock mitral valve and papillary muscle hypoplasia. The etiology of mitral regurgitation in the pediatric population can also be related to rheumatic valve disease, endocarditis, trauma, postballoon valvotomy, postvalvuloplasty for mitral stenosis, dysplastic valve (Marfan's and non-Marfan's), and secondary to ischemic papillary muscle dysfunction associated with an abnormal left coronary artery (35,36). Most commonly, regurgitation is seen in the setting of complete or partial (heart with partitioned tricuspid and mitral annuli) atrioventricular septal defect. In fact, most of these patients have some degree of AV valve regurgitation preoperatively and 10% to 20% of them will develop severe left AV valve regurgitation late postoperatively. Not closing the cleft has been identified as a risk factor.

Pathophysiology: Similar to mitral regurgitation in adults.

Diagnosis: Echocardiography is the diagnostic tool of choice (37). Cardiac catheterization should be reserved for when there is concern about pulmonary hypertension, LV dysfunction and the need to measure LV end-diastolic pressure.

Natural history: Isolated congenital mitral insufficiency is often only moderate in severity in infancy and only 50% of patients will require surgery before the age of five (30).

Indications for intervention: Surgery should be performed when medical treatment fails to control heart failure or in the presence of deteriorating LV systolic function. Failure to thrive should be considered a symptom of heart failure. Mitral regurgitation from AV septal defect, mitral valve prolapse, rheumatic fever or inflammatory disease can usually be reduced by mitral annuloplasty. MVR with mechanical prosthesis or bioprosthesis may be necessary. If repair is likely, surgery for severe mitral regurgitation can be performed in the absence of congestive heart failure or LV dysfunction. Valve repair should be the preferred option in small children even if the result is suboptimal. Valve

TABLE 53
Recommendations for surgery in children with congenital mitral regurgitation

Indication	Class	
1. New York Heart Association (NYHA) functional class III or IV symptoms	I	B
2. Congestive heart failure despite maximal medical therapy	I	B
3. Left ventricular systolic dysfunction		
Ejection fraction ≤0.60	I	C
Left ventricular systolic volume >60 mL/m^2		
4. NYHA class I or II with preserved left ventricular systolic function when valve repair rather than valve replacement likely	IIB	C

TABLE 54
Recommendations for mitral valve surgery in the adolescents or young adults with congenital mitral regurgitation

Indication	Class	
1. New York Heart Association (NYHA) functional class III or IV symptoms	I	B
2. Asymptomatic patients with left ventricular (LV) systolic dysfunction (ejection fraction ≤0.60)	I	C
3. NYHA functional class II symptoms with preserved LV systolic function if valve repair rather than replacement is likely	IIa	C
4. Asymptomatic patients with preserved LV systolic function in whom valve repair is highly likely	IIb	C
Contraindication		
5. Asymptomatic patient with preserved LV systolic function in whom valve replacement is highly likely	III	C

repair can be facilitated by artificial chordae of expanded polytetrafluoroethylene sutures; this procedure has been found to be safe and effective. The artificial chordae can delay or possibly prevent the need for mechanical prostheses (38). Mechanical prostheses may require replacement in a growing child; a larger prosthesis can be implanted because the mitral valve annulus can grow even when fixed to a prosthetic sewing ring. A mitral valve repair procedure can be supported by a partial plication annuloplasty that also allows the mitral annulus to grow (39).

Intra-atrial re-entrant tachycardia is an indication for radiofrequency ablation after congenital heart surgery (40-43). The macrore-entrant tachyarrhythmias can occur after repair or palliative procedures (44). Radiofrequency catheter ablation can be used for control of tachyarrhythmias (Tables 53 and 54).

Pulmonary stenosis

Etiology: Most cases of pulmonary stenosis are congenital in origin. The valve is either conical or dome-shaped with fusion of the leaflets. The valve may be thickened and dysplastic with poorly mobile leaflets and the annulus may be hypoplastic.

Diagnosis: Diagnosis and severity assessment is made by two-dimensional and Doppler echocardiography (45).

Natural history: The mode of presentation is either in the newborn period with symptomatic critical pulmonary stenosis or later when an asymptomatic patient is referred for murmur evaluation (46). The young adult with long standing severe obstruction may have dyspnea and fatigue. Exertional syncope or lightheadedness may occur but sudden death is unusual. In the presence of patent foramen ovale or atrial septal defect, RV hypertrophy and decreased RV compliance may be associated with right to left shunting and desaturation. The Natural History of Congenital Heart Defects study (10,47) revealed that the 25-year survival rate (greater than 95%) was comparable with the age- and sex-matched expected survival. Of the patients presenting with a gradient greater than 50 mmHg, only 20% required valvotomy for a follow-up period of 25 years. Higher risk of mortality occurred with age greater than 12 years or cardiomegaly at time of entry in the study. For patients with gradient less than 25 mmHg at entry, 96% were free of surgery over a 25-year period.

Indications for intervention: The procedure of choice is percutaneous balloon valvotomy for symptomatic patients or those with high right ventricle to pulmonary artery peak gradients (48-50). The reduction in gradient and survival is similar with percutaneous balloon or surgical valvotomy. Surgery is still required for the dysplastic valve often seen in Noonan's syndrome. Balloon valvotomy has become the procedure of choice for newborns with a dysplastic valve or associated hypoplastic RV, or hypoplastic tricuspid and pulmonary valve annulus, because growth potential has been reported (51-53). Some newborns with a noncompliant RV may require prolonged prostaglandin infusion with or without the addition of beta blockade.

If balloon valvotomy is unsuccessful or unavailable, the surgical options are either open valvotomy with CPB or inflow occlusion, or closed valvotomy.

Special consideration: A newborn with critical pulmonary stenosis who remains cyanotic after balloon valvotomy may require a systemic-pulmonary shunt (54). A transannular patch may be necessary initially or subsequently, but an initial transannular patch without a shunt is a risk factor for postoperative hypoxia (Tables 55 and 56).

Good results have also been reported with balloon valvotomy in adults. Infants need close follow-up following dilation because reintervention is needed in 12% to 25% of patients in the first two years of life.

Pulmonary regurgitation

Etiology: Isolated pulmonary regurgitation from idiopathic pulmonary dilation is an uncommon congenital lesion. Mild to moderate regurgitation can be associated with an abnormal appearing bicuspid pulmonary valve with elongated leaflets and no evidence of pulmonary stenosis. Usually, significant pulmonary regurgitation will be secondary to intervention for pulmonary stenosis or Tetralogy of Fallot.

Diagnosis: Serial echocardiography should assess for progressive dilation of the RV, appearance of tricuspid regurgitation, subjective evaluation of RV function and LV ejection fraction.

TABLE 55
Recommendations for intervention in children with pulmonary stenosis (balloon valvotomy or surgery)

Indication	Class	
1. Symptomatic infant with critical pulmonary stenosis	I	B
2. Patient with NYHA class III to IV (exertional dyspnea, angina, syncope or presyncope) and critical pulmonary stenosis	I	B
3. Asymptomatic patient with normal cardiac output (estimated clinically or by catheterization)		
a) RV-PA gradient >50 mmHg	I	B
b) RV-PA gradient 40 to 49 mmHg	IIA	C
c) RV-PA gradient 30 to 40 mmHg	IIB	C
Contraindication		
4. Asymptomatic patient with normal cardiac output (estimated clinically or by catheterization) with RV-PA gradient <30 mmHg	III	C

NYHA New York Heart Association; RV-PA Right ventricular to pulmonary artery

TABLE 56
Recommendations for intervention in adolescents or young adults with pulmonary stenosis (balloon valvotomy or surgery)

Indication	Class	
1. Patients with exertional dyspnea, syncope, or presyncope	I	B
2. Asymptomatic patients with normal cardiac output (estimated clinically or determined by catheterization)		
a) RV-PA peak gradient >50 mmHg	I	B
b) RV-PA peak gradient 40 to 49 mmHg	IIa	C
c) RV-PA peak gradient 30 to 39 mmHg	IIb	C
Contraindication		
2. d) RV-PA peak gradient <30 mmHg	III	C

RV-PA Right ventricular to pulmonary artery

Ideally, a more objective assessment of RV volume and function should be done either by echocardiography or nuclear medicine. Patients with long standing moderate to severe pulmonary regurgitation should have annual Holter monitoring to diagnose malignant ventricular arrhythmia.

Natural history: The Natural History of Congenital Heart Defects study (47) identified moderate to severe pulmonary regurgitation following balloon valvotomy for pulmonary stenosis in 6% of patients clinically and 20% by echocardiography. Pulmonary regurgitation also commonly occurs after successful repair of Tetralogy of Fallot but the natural history is less well documented and still in evolution (55,56). It is known that postrepair survival is possible for 35 years after surgery (57). Late sudden death varies from 2.5% to 6% and some reports link it to RV dilation and ventricular ectopy. Chronic long term moderate to severe pulmonary regurgitation is associated with dilation of the RV, diminished RV systolic performance, inability to augment cardiac output with exercise and congestive heart failure. Therefore, it appears that an increasing number of these patients will require reoperation for chronic severe pulmonary regurgitation. Also, increased PAP from LV dysfunction or residual peripheral pulmonary artery stenosis will increase the amount of regurgitation.

Indications for surgery: Surgical management of chronic severe pulmonary regurgitation should be related to complications of congestive heart failure and documented ventricular ectopy. Pulmonary valve replacement, usually with an allograft pulmonary root, should be performed but no long term documentation is available (26). The allograft conduit for the RV outflow tract may be tissue engineered with autologous cells. This could be a major breakthrough, providing a genetic coat against immulogical and biochemical stress. Other options are a stentless bioprosthesis or a fashioned monocusp valve. Mechanical prostheses should be avoided in the RV outflow tract reconstruction (Table 57).

Special consideration: Close follow-up is required for patients more than 25 years following repair and patients with QRS duration greater than 180 m/s.

Tricuspid valve disease

Etiology: The etiology of congenital tricuspid valve regurgitation can be divided into two major groups: Ebstein's anomaly and non-Ebstein's malformations (58,59). The latter group includes diseases such as unguarded tricuspid valve, tricuspid regurgitation secondary to RV dysfunction due to variable conditions, and tricuspid valve dysplasia. Although tricuspid valve dysplasia is anatomically different from the Ebstein's anomaly, it follows the same clinical patterns and therefore should be managed similarly.

Diagnosis: The diagnosis and characterization of tricuspid valve leaflet attachments and insertions in Ebstein's anomaly are accurately made by echocardiography (60,61). Specific echocardiographic diagnostic criteria and quantitative assessment of the severity of the anomaly are available, have been proven to be of prognostic value, and should therefore be followed. There is little additional role for cardiac catheterization in the diagnosis of this malformation.

Natural history: The clinical presentation of Ebstein's anomaly in the adolescent or young adult varies considerably from the neonatal presentation (62). Although it carries a better outcome than the neonatal group, the natural history still reveals a suboptimal survival rate. Ebstein's anomaly diagnosed antenatally and in the neonatal period carries a grim prognosis with survival rate of approximately 60% depending on the presence of known risk factors and the degree of atrialization of the right ventricle (63). In view of the outcome of the critical neonatal Ebstein's anomaly, special recommendations can be made for management.

TABLE 57
Recommendations for pulmonary valve replacement in chronic severe pulmonary regurgitation

Indication	Class	
1. Ventricular tachycardia with moderate to severe pulmonary regurgitation	I	C
2. New onset tricuspid regurgitation with moderate to severe pulmonary regurgitation	IIa	C
3. Worsening New York Heart Association class with right ventricular dilation	IIa	C

TABLE 58
Recommendations for surgery in neonates and pediatric patients for Ebstein's anomaly with severe tricuspid regurgitation

Indication	Class	
1. Unstable cyanotic newborn in congestive heart failure, in need of mechanical ventilation, prostaglandin dependent and failed medical therapy	I	B
2. Congestive heart failure	I	B
3. Deteriorating exercise capacity (New York Heart Association functional class III or IV)	I	B
4. Progressive cyanosis with arterial saturation <80% at rest or with exercise	I	B
5. Asymptomatic patient with increasing tricuspid insufficiency and cardiothoracic ratio	II	C

TABLE 59
Recommendations for surgery in adolescents or young adults with Ebstein's anomaly and severe tricuspid regurgitation

Indication	Class	
1. Congestive heart failure	I	B
2. Deteriorating exercise capacity (NYHA functional class III or IV)	I	B
3. Progressive cyanosis with arterial saturation <80% at rest or with exercise	I	B
4. Progressive cardiac enlargement with cardiothoracic ratio >60%	IIa	C
5. Systemic emboli despite adequate anticoagulation	IIa	C
6. NYHA functional class II symptoms with valve probably reparable	IIa	C
7. Atrial fibrillation	IIa	C
8. Deteriorating exercise tolerance (NYHA functional class II)	IIa	C
9. Asymptomatic patients with increasing heart size	IIb	C
Contraindication		
Asymptomatic patients with stable heart size	III	C

NYHA New York Heart Association

In Ebstein's anomaly, there is inferior displacement of the septal and posterior leaflets of the valve into the right ventricle (64-70). If there is significant adherence of the leaflets to the RV wall, the normal or relatively normal anterior leaflet fails to coapt with the abnormal posterior leaflet and severe tricuspid regurgitation is the result. When the valve leaflets are not adherent with redundancy and prolapse, there is associated varying degrees of tricuspid regurgitation.

The varying severity of leaflet abnormalities creates varying degrees of tricuspid regurgitation. Some neonates have severe tricuspid regurgitation in the perinatal period when pulmonary vascular resistance and RV pressures are elevated. Most cases have a patent foramen ovale and right to left shunting and hypoxemia can occur with tricuspid regurgitation and high RA pressures (71). The clinical presentation is varied from an asymptomatic, acyanotic state with no atrial arrhythmias to that of cyanosis, RV dysfunction and congestive failure, and atrial arrhythmias.

Indications for surgery

The critical neonate may be an unstable cyanotic newborn with congestive heart failure in need of mechanical ventilation, prostaglandin dependence and massive cardiomegaly. Aggressive medical treatment aimed to support ventricular function and decrease pulmonary resistance must be considered. If medical stabilization is not achieved, surgical intervention converting the Ebstein's anomaly into tricuspid atresia with patch closure of the tricuspid valve, enlargement of the atrial septal defect, and construction of an aorta-pulmonary shunt, can be performed (71). If stability is achieved by medical treatment, avoidance or delay in surgical intervention can be possible. If the valve stenosis needs to be addressed surgically, repair should always be considered the best option over replacement (66-70). In order to improve the success of the tricuspid valve repair, a combined cavopulmonary anastomosis may be beneficial, especially if the functional right ventricle is less than 30% of normal size. However, if replacement is required, there is no clear evidence favouring a bioprosthesis or a mechanical prosthesis in the tricuspid position.

Tricuspid stenosis is uncommon and caused by various etiologies. The management is tricuspid valve balloon valvotomy but severe tricuspid regurgitation is a common consequence of the procedure and results are poor. (Tables 58 and 59).

Anticoagulation for mechanical prostheses

Anticoagulation remains strongly recommended for the management of patients in the pediatric age group who have mechanical prostheses (72).

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SECTION VII: VALVULAR SURGERY IN THE ELDERLY

The definition of elderly is 75 years of age or older. The potential for surgical management of valvular disease in the elderly differs according to valve position and valve lesion. The elderly patient is likely to have comorbid disorders that will impact on outcome. The primary purpose of valvular surgery in the elderly is to improve quality of life and not necessarily to improve survival except in aortic stenosis. The decision to proceed with valve surgery in the elderly is therefore dependent on many factors including the desires and expectations of the patient. The most common indication is severe aortic stenosis with or without concomitant CAD.

Aortic stenosis

The predominant cause of aortic stenosis in the elderly is degenerative calcific disease of the normal trileaflet valve. Valve replacement must be considered in the elderly who have symptomatic aortic stenosis because balloon valvotomy is not an acceptable alternative, although the latter may serve as a 'bridge' to replacement in patients with acute pulmonary edema and possibly in those with cardiogenic shock. The optimal bridge to surgery for patients with pulmonary edema and cardiogenic shock are inotropes and vasoconstrictors. Valve replacement is technically feasible at any age for severe aortic stenosis. Elderly patients with severe aortic stenosis and absence of ventricular dysfunction and CAD can expect a good outcome. The predictors of surgical survival include CAD, ventricular dysfunction, and renal and pulmonary impairment. Surgery is inappropriate in patients with advanced cancer and neurological deficits from cerebrovascular accidents, as well as in deconditioned and debilitated patients.

The mortality for elderly patients with isolated AVR is 2% to 12% and doubles to 19% to 24% with concomitant coronary artery bypass. There is no exact method to consider all the relevant factors to identify high and low risk patients. The decision to proceed with AVR is an overall evaluation of the potential for improvement of symptoms and survival with medical management, and the mortality and morbidity associated with surgery. There is documentation that midterm survival following AVR is satisfactory whether or not coronary artery bypass was an accompanying procedure. Bioprostheses are generally used in the elderly, but consideration must always be given to match durability of bioprostheses and longevity of the patient to avoid the need for late reoperation.

Special surgical considerations

The elderly may present with heavy calcification of valve, annulus and aortic root that requires extensive debridement. Extreme calcification may necessitate aortic root replacement and in this situation a stentless porcine root prosthesis would be advised rather than a mechanical valved conduit, to avoid anticoagulation. The elderly female, with a narrow LVOT and small aortic annulus, may require special consideration and possible enlargement of the annulus to implant a satisfactory size prosthesis. The alternative is a supra-annular bioprosthesis, either porcine or pericardial. The externally mounted 19 mm pericardial bioprosthesis optimizes hemodynamics. A further alternative is implantation of a stentless porcine bioprosthesis (subcoronary position) but extensive aortic sinus calcification does create a relative contraindication.

Bioprostheses are particularly satisfactory in the elderly with excellent 10- and 15-year durability and avoidance of anticoagulants and associated bleeding complications.

Aortic regurgitation

Pure aortic regurgitation is uncommon in the elderly. The vast majority of elderly patients with aortic valve disease have aortic stenosis or combined aortic stenosis and regurgitation. Elderly patients do less well with aortic regurgitation than patients at earlier ages. Patients over 75 years of age develop symptoms and LV dysfunction at an earlier stage of LV dilation. The elderly patient has more persistent ventricular dysfunction and congestive heart failure after surgery and has worse postoperative survival. Many elderly patients have concomitant CAD that may influence the presence and severity of LV dysfunction. The asymptomatic or mildly symptomatic patients with LV dysfunction (ejection fraction below normal at rest) should be considered for AVR depending on their age and health. The patients with advanced symptoms, severe LV dysfunction and extreme dilation are not candidates for AVR.

Mitral stenosis

Symptomatic mitral stenosis is now more common in the elderly because of the changing natural history of rheumatic fever. Older patients have heavy calcification and fibrosis of the mitral leaflets and considerable subvalvular fusion. Idiopathic calcification of the annulus, particularly the posterior annulus, is a common entity in the elderly.

MVR in the elderly carries a risk of 15% to 20%, often contributed to by comorbid disease. Percutaneous mitral balloon valvotomy may be considered in these patients who are at increased risk of surgery but procedural success is low (less than 50%) and mortality and complications are high.

Mitral regurgitation

Elderly patients generally do poorly with surgery for mitral regurgitation. The operative mortality is high and survival is reduced, especially if concomitant coronary artery bypass is needed. Mitral valve surgery has been documented to be performed with acceptable early and midterm outcomes if repair is possible or the subvalvular apparatus is preserved during MVR. Survival is primarily compromised by advanced symptomatology and LV dysfunction. There is limited indication for surgery in an attempt to preserve ventricular function because the aim of surgery in the elderly is to improve quality of life, not to prolong survival.

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SECTION VIII: MANAGEMENT OF VALVULAR DISEASE IN PREGNANCY

Cardiac disease complicates approximately 0.5% to 1% of all pregnancies. Increasing numbers of women with heart disease will be contemplating pregnancy as a result of advances in the diagnosis and treatment of heart disease during childhood and early adulthood (1-13). Virtually all studies of pregnancy outcomes in women with heart disease are retrospective with ascertainment bias and nonstandardized assessment of outcomes. These studies have come from single institutions or groups of tertiary care institutions with institutional selection biases. Most studies are case series and there are few large cohort studies. There is a need for large prospective observational studies and randomized clinical trials.

Physiological changes during pregnancy

The changes in circulatory physiology during pregnancy are well delineated and place increasing demands on the cardiovascular system (2,3,14). The evaluation and management of valvular heart disease in pregnancy demands an understanding of these normal physiological changes associated with gestation, labour, delivery and the early postpartum period. During pregnancy, hormonally mediated changes in blood volume, red cell mass and heart rate result in a marked increase in cardiac output that peaks during the second trimester and remains constant through the remainder of the pregnancy. The increase in cardiac output may reach 30% to 60% above nonpregnant levels. There are decreases in peripheral vascular resistance and blood pressure. During labour and delivery, pain and uterine contractions result in additional increases in cardiac output and blood pressure. Immediately following delivery, relief of caval compression and autotransfusion from the emptied and contracted uterus produce a further increase in cardiac output. The hemodynamic changes of pregnancy may not be fully resolved until the sixth postpartum month.

Pregnancy is also associated with a hypercoagulable state with increased concentration of clotting factors, rapid platelet turnover and depressed activity of the fibrinolytic system.

Echocardiographic characteristics in normal pregnancy

There are increased LV and RV dimensions in normal pregnancy. Systolic function of the left ventricle is preserved with normal contractility and ejection fraction. There are mild increases of both left and RA size and increased diameter of the tricuspid annulus. Small pleural effusions are normal findings. Functional tricuspid, pulmonary and mitral insufficiency are often identified (14).

Risk stratification of women with valvular disease

Maternal death during pregnancy in women with heart disease is rare except in those with Eisenmenger's syndrome or pulmonary vascular obstructive disease. However, pregnant women with valvular heart disease remain at risk for cardiac morbid events such as congestive heart failure, arrhythmias or stroke.

Risk stratification and counselling of women with valvular heart disease is best accomplished before conception (15). In a 1997 published study (15), poor functional status (NYHA class greater than II) or cyanosis, myocardial dysfunction, left heart obstruction, prior arrhythmia and prior cardiac events were independent predictors of maternal cardiac complications. A risk index that related the number of predictors to increasing rate of cardiac complications during pregnancy has been developed from this retrospective evaluation. The risk index determined by this retrospective study has been assessed in a prospective multicentre study of pregnancy outcomes in women with heart disease (16). The study has identified four predictors of primary cardiac events — prior cardiac event (heart failure, transient ischemic attack or stroke before pregnancy) or arrhythmia, baseline NYHA class greater than II or cyanosis, left heart obstruction (MVA less than 2 cm^2, aortic valve area (AVA) less than 1.5 cm^2 or peak LVOT gradient greater than 30 mmHg by echocardiography), and reduced systemic ventricular systolic function (ejection fraction less than 40%). The predictors of primary cardiac events were incorporated into a revised risk index in which each pregnancy was assigned one point for each predictor when present. The estimated risk of a cardiac event in pregnancies with zero, one and greater than one points was determined at 5%, 27% and 75%, respectively.

Poor maternal functional class or cyanosis has been known to also be predictive of adverse neonatal events (15,17). In the prospective study, the five predictors of neonatal events were NYHA class greater than II or cyanosis at baseline prenatal time, maternal left heart obstruction, smoking during pregnancy, multiple gestations and use of anticoagulants throughout pregnancy (16). The fetal or neonatal death rate with none of the predictors is 2%, and rises with one or more predictors.

Pregnant women with heart disease are at increased risk for both neonatal and cardiovascular complications (18-20). The maternal cardiac status and risk of cardiac complications during pregnancy have been classified as low risk, intermediate risk and high risk (19,20).

Low risk:

- small left to right shunts;
- repaired lesions without residual cardiac dysfunction;
- isolated mitral valve prolapse without significant regurgitation;
- bicuspid aortic valve without stenosis;
- mild to moderate pulmonic stenosis; and
- valvular regurgitation with normal ventricular systolic function.

Intermediate risk:

- unrepaired or palliated cyanotic congential heart disease;
- large left to right shunt;
- uncorrected coarctation of the aorta;
- mitral stenosis or aortic stenosis;
- mechanical prosthetic valves;
- severe pulmonic stenosis;
- moderate to severe systemic ventricular dysfunction; and
- history of peripartum cardiomyopathy with no residual ventricular dysfunction.

High risk:

- NYHA class III or IV symptoms;
- severe pulmonary hypertension;
- Marfan's syndrome with aortic root or major valvular involvement;
- severe aortic stenosis; and
- history of peripartum cardiomyopathy with residual ventricular dysfunction.

Specific valvular lesions

Obstructive valvular lesions are most affected by the hemodynamic changes of pregnancy. Left-sided obstructions (aortic stenosis and mitral stenosis) tend to manifest problems more than right-sided obstructions. Regurgitant lesions (aortic regurgitation and mitral regurgitation) are usually well tolerated in pregnancy because of LV unloading secondary to the physiological fall in systemic vascular resistance.

Chronic rheumatic valvular disease should be managed individually according to the site and severity of the lesion.

Mitral stenosis is the most common valvular lesion encountered during pregnancy. The severity of mitral valve obstruction is exacerbated by the hypervolemia and tachycardia associated with pregnancy. The majority of patients with moderate to severe mitral stenosis demonstrate worsening of clinical status during pregnancy. The resultant elevation in LA pressure increases the likelihood of atrial fibrillation. Atrial fibrillation is a frequent precipitating factor of heart failure in pregnant patients with mitral stenosis.

Patients with mild to moderate mitral stenosis can almost always be managed with diuretics and beta adrenergic receptor blockers. Digoxin is useful to control ventricular rate in atrial fibrillation; anticoagulation should also be initiated. Hemodynamic monitoring during labour and vaginal delivery in women with moderate or severe mitral stenosis (MVA less than 1.5 m^2) may provide an additional modality for monitoring the mother.

Repair or replacement of the mitral valve during pregnancy, however, may be indicated in some patients with severe symptomatic mitral stenosis (MVA less than 1.0 cm^2) in spite of adequate medical therapy. Closed mitral valvotomy is currently practised only in developing countries. Percutaneous mitral balloon valvotomy under echocardiographic guidance is the procedure of choice in developed countries when aggressive medical measures are unsuccessful (21-25). Closed procedures are used for isolated mitral stenosis with commissural fusion but well preserved subvalvular apparatus. Extensive valve calcification or subvavular fusion are relative contraindications and the procedures should not be performed in the presence of LA thrombus. The procedures should be avoided if possible during the first trimester. Conventional mitral valve surgery is recommended when relative or absolute contraindications to balloon valvotomy exist.

Aortic stenosis in pregnancy, whether due to rheumatic aortic stenosis or congenital aortic stenosis, has a similar outcome. Women with symptomatic aortic stenosis should delay pregnancy until after surgical correction. However, the absence of symptoms antepartum is not sufficient assurance that pregnancy will be well tolerated.

Symptomatic patients with AVA less than 1.0 cm^2, especially if resistant to medical therapy, may require termination of pregnancy, or repair or replacement of the aortic valve. The most common morphology of aortic valve disease during pregnancy is bicuspid aortic valve. Percutaneous balloon valvotomy may provide short term palliation until valve replacement can be performed.

In pregnant women with severe aortic stenosis, the limited ability to augment cardiac output may result in abnormal elevation of LV systolic and filling pressures which may precipitate or exacerbate heart failure or ischemia. In addition, the noncompliant, hypertrophied ventricle is sensitive to falls in preload (as may occur due to inferior vena cava compression in late pregnancy, vasodilator effects of anesthetic agents, peripartum blood loss or bearing down maneuvers), leading to drops in cardiac output or hypotension.

Mitral regurgitation is usually well tolerated in pregnancy due to the physiological fall in systemic vascular resistance. Further afterload reduction management with hydralazine is safe for use in pregnancy including prevention of hemodynamic deterioration during labour.

Aortic regurgitation, similar to mitral regurgitation, is also well tolerated during pregnancy. This is related to the reduced systemic vascular resistance and increased heart rate. Hydralazine is also beneficial during pregnancy.

Marfan's syndrome in women with pregnancy poses a twofold problem: the child inheriting the condition and potential catastrophic and often lethal acute aortic dissection (26-28). The complications include dilation of the ascending aorta leading to aortic regurgitation and heart failure, and proximal and distal aortic dissection. The majority of patients develop these complications in the later phase of pregnancy. Women with Marfan's syndrome require appropriate preconception counselling; women already pregnant with aortic dilation should seriously consider early abortion. Women with aortic dilation and acute dissection should be delivered by cesarean section accompanying definitive surgical management. Women with prior surgery for ascending aortic dilation may still be at risk for distal dissection due to the generalized nature of the aortopathy in Marfan's syndrome.

Choice of prosthesis for women of childbearing age

The risk to pregnancy in women with a valve prosthesis is multifactorial (29-31). The potential problems are related to the hypercoagulable state of pregnancy and increased risk of thromboembolic events, increased hemodynamic volume, risk to the fetus from anticoagulants and the accelerated deterioration of bioprostheses. Normally functioning biological and mechanical prostheses can tolerate the hemodynamic load of the state of pregnancy. Bioprostheses during the childbearing years are subject to accelerated structural deterioration but pregnancy does not advance that deterioration (32-34). The risk of warfarin embryopathy is 4% to 10% but may be reduced with low dose warfarin that is acceptable with current generation mechanical prostheses (35). The hypercoagulable state of pregnancy, on the other hand, increases the risk of prosthesis thrombosis and thromboembolic events. When warfarin is replaced by heparin between the sixth to 12th week of gestation and after the 36th week, there is an increased risk of prosthesis thrombosis and maternal hemorrhage (36). Warfarin is also associated with an increased risk of spontaneous abortion, prematurity and stillbirth. The livebirth rate is lower with mechanical prostheses than biological prostheses.

TABLE 60
Recommendations for type of prostheses in women of childbearing age

Indication		Class	
Biological prostheses	women who otherwise would not require anticoagulation for other indications	II a	C
Mechanical prostheses	women who require anticoagulation for other indications	II b	C

Women who have received mechanical prostheses must be fully informed of the risks of warfarin and heparin, and adhere to the recommended guidelines for anticoagulation

TABLE 61
Recommendations for anticoagulation during pregnancy: Weeks one through 35 in patients with mechanical prosthetic valves

Indication	Class	
1. The decision whether to use heparin during the first trimester or to continue oral anticoagulation throughout pregnancy should be made after full discussion with the patient and her partner; if she chooses to change to heparin for the first trimester, she should be made aware that heparin is less safe for her, with a higher risk of both thrombosis and bleeding, and that any risk to the mother also jeopardizes the baby*	I	C
2. High-risk women (a history of thromboembolism or an older generation mechanical prosthesis in the mitral position) who choose not to take warfarin during the first trimester should receive continuous unfractionated heparin intravenously in a dose to prolong the midinterval (6 h after dosing) prothrombin time to 2 to 3 times control. Transition to warfarin can occur thereafter	I	C
3. In patients receiving warfarin, INR should be maintained between 2.0 and 3.0 with the lowest possible dose of warfarin, and low-dose acetylsalicylic acid should be added	IIa	C
4. Women at low risk (no history of thromboembolism, newer low-profile prosthesis) may be managed with adjusted dose subcutaneous heparin (17,500 to 20,000 U bid) to prolong the midinterval (6 h after dosing) prothrombin time to 2 to 3 times control	IIb	C

**From the European Society of Cardiology Guidelines for Prevention of Thromboembolic Events in Valvular Heart Disease. Adapted from American College of Cardiology and American Heart Association Guidelines (37). bid Twice daily; INR International normalization ratio*

TABLE 62
Recommendations for anticoagulation during pregnancy: After week 36 in patients with mechanical prosthetic valves

Indication	Class	
1. Warfarin should be stopped no later than week 36 and heparin substituted in anticipation of labour	IIa	C
2. If labour begins during treatment with warfarin, a cesarean section should be performed	IIa	C
3. In the absence of significant bleeding, heparin can be resumed 4 to 6 h after delivery and warfarin begun orally	IIa	C

Adapted from American College of Cardiology and American Heart Association Guidelines (37)

Failure of biological prostheses can occur during pregnancy but pregnancy has not been shown to accelerate failure (32-34). Pregnancies in women with biological prostheses require planned conception within a recommended time interval of four to six years after valve implantation, especially for mitral prostheses. The reoperative mortality for elective and urgent rereplacement of failed bioprostheses in the current era is less than 3%.

The optimal type of prosthesis, biological or mechanical, for women considering childbearing has not been fully defined (37-39). Autografts and heterografts (porcine and bovine pericardial) can be used for AVR and heterografts for MVR if reconstruction is not feasible (40). On the other hand, mechanical prostheses can be used at all positions (39) (Tables 60, 61 and 62).

There remains controversy over the best anticoagulant regime at different stages of pregnancy (30,31,36,41). Oral anticoagulation with warfarin is better accepted by patients and is effective. However, teratogenicity occurs during organogenesis, producing warfarin embryopathy. Uteroplacental bleeding can occur with warfarin, a cause of increased fetal loss. Fatal intracranial hemorrhage during vaginal delivery is a risk with warfarin unless it has been stopped at least two weeks before labour.

Women of childbearing potential with valvular heart disease have problems because of lack of relative data on the efficacy and safety of antithrombotic therapy during pregnancy. In a retrospective review of outcomes with mechanical valves, warfarin was found to be safe and not associated with more thromboembolic and bleeding complications (42). Mechanical valves are resistant to moderate doses of heparin and there is the need to use adequate heparin doses. There must be adequate initial heparinization and stringent monitoring.

There are insufficient grounds to make definite recommendations about optimal antithrombotic therapy with mechanical valves. There remain concerns about fetal safety with warfarin, efficacy of subcutaneous heparin for preventing thromboembolic complications and risks of maternal bleeding with various regimens. Warfarin should be avoided between six and 12 weeks of gestation (to avoid embryopathy) and close to term (to avoid delivery of an anticoagulated fetus). The target international normalization ratio (INR) should be 3.0 (range 2.5 to 3.5) for most mechanical valves but 2.0 to 3.0 for bileaflet aortic valves, provided there is absence of atrial fibrillation or LV dysfunction (or heparin is used throughout pregnancy).

Adjusted doses of subcutaneous heparin have no teratogenic effects because the drug does not cross the placenta (43). Maternal thrombocytopenia is a risk, and maternal osteoporosis may be seen with use for more than three months. Low molecular weight heparin may be equally effective and easier to administer (44-46). Claims of inadequate effectiveness of heparin in patients with mechanical prostheses have been countered by arguments that inadequate doses were used; clinical trials examining the optimal anticoagulation strategy in these patients have not been performed. The American College of Chest Physicians consensus conference recommended heparin at least during the first 13 weeks and after the middle of the third trimester (30,31). Patients have the option of continuing on heparin throughout pregnancy or using warfarin from the 13th week to the middle of the third trimester. This approach minimizes, but does not eliminate, the teratogenic effects of warfarin. Full doses of heparin are effective to prevent systemic embolus. There are two approaches to therapy. First, heparin is administered throughout pregnancy every 12 h by subcutaneous injection to keep midinterval activated partial thromboplastin time (APTT) in therapeutic range (at least twice control) or an anti-αa heparin level of 0.35 to 0.70 U/mL. The second approach is to use heparin until the 13th week, to change to warfarin until the middle of the third trimester and then restart heparin therapy until delivery. The latter approach might avoid warfarin embryopathy but other fetopathic effects (eg, central nervous system abnormalitites) are still possible. Therefore, before this approach is recommended, the potential risks should be explained to patients. The 2002 American College of Chest Physicians recommendations suggest low molecular weight heparin as an alternative but acknowledge the lack of systematic data in the area (47). The ACC and AHA guidelines are influenced by the European guidelines and they are firmly in the 'coumadin is good, heparin is bad' camp (37).

Cardiac surgery during pregnancy

Cardiac surgery during pregnancy has been performed with an astonishingly low 3% to 4% maternal mortality but a high 10% to 20% fetal mortality (8,48-50). Surgery, on the other hand, has been recommended to be undertaken as soon as intervention is deemed inevitable.

The pathophysiological process of extracorporeal circulation provides a strong stimulus for uterine contractions, an important predictor of fetal death. Uterine contractions contribute to fetal hypoperfusion and bradycardia. Placental perfusion is dependent on a mean perfusion pressure of 70 mmHg or greater when uterus is in the relaxed state. The strength of uterine contractions causes a rise in intra-amniotic fluid pressure and also contributes to fetal bradycardia. Uterine monitoring and pharmaceutical therapy are aimed at prevention of fetal hypoperfusion and hypoxia. The loss of peripheral vascular resistance at the beginning of CPB causes maternal hypotension, placental hypoperfusion and fetal hypoxia manifested by bradycardia. Hypothermia must be avoided on CPB to prevent deterioration of placental gas exchange, rise in placental vascular resistance and impaired fetal perfusion. CPB and hypothermia cause loss of the diastolic component of umbilical artery flow. The return of maternal circulation reverts the bradycardia to compensatory tachycardia.

The conduct of CPB must minimize fetal risk through adequate uterine blood supply. To maintain placental perfusion, CPB flows must be greater than 2.7 L/m^2, perfusion pressure greater than 50 mmHg and temperature maintained at normothermia.

Cardiac surgery should be conducted during the third trimester, however, there is substantial risk of fetal mortality even during the second and third trimesters. Neonates of less than 26 weeks gestation have extremely high mortality and a 20% risk of neurological damage in survivors. Delivery after 26 to 30 weeks gestation provides an expected survival of 80% and, after 30 weeks, 99% of premature infants are expected to survive. The mother should be treated medically for as long as possible and, after 28 weeks, given combined cardiac surgery and elective cesarean section. The cesarean section should be performed immediately before CPB (Tables 63, 64 and 65).

TABLE 63
Recommendations for cardiac surgery in childbearing women

Indication	Class	
1. Recognition and correction of cardiac anomalies before planned pregnancy	I	B
2. Urgent intervention first trimester	I	B
Interventional cardiology or closed cardiac surgery		
3. Fetus >28 weeks gestation	II a	B
Cesarean section		
Cardiac correction on cardiopulmonary bypass		
4. Fetus <28 weeks gestation and fetus in utero and fetal monitoring	II a	B
Cardiopulmonary bypass time minimal		
High flow >2.7 L/min/m^2		
High pressure 60 mmHg		
Normothermic perfusion		
Pharmacological manipulation to improve placental perfusion		
Fetal bradycardia increase pump flow and perfusion pressure		
Uterine contractions manage proven pharmacological agent		
5. Intrauterine death	I	B
Avoid maternal hemodynamic instability postoperative		
Avoid risks of hemorrhage spontaneous abortion; amniotic fluid embolism and disseminated intravascular coagulation		

Adapted from Parry et al (8)

TABLE 64
Recommendations for valvular intervention before conception

Indication		Class	
1. Severe mitral stenosis and considering pregnancy:			
Symptomatic	Percutaneous balloon valvotomy or mitral reconstruction or replacement depending on valvular morphology	I	B
Asymptomatic	Exercise testing to assess functional capacity and individualize therapy	IIa	C
2. Severe aortic stenosis and considering pregnancy:			
Symptomatic	Surgical intervention before conception	I	B
Asymptomatic	Individualize therapy according to functional status and surgical intervention. Prophylactic intervention based on risk to benefit ratio	IIa	C

TABLE 65
Recommendations for valvular intervention during pregnancy

Indication	Procedure	Class	
1. Symptomatic severe mitral stenosis refractory to medical therapy, with consideration of valve morphology and interventional expertise	Percutaneous balloon valvotomy (optimal timing early second trimester). Patients with asymptomatic severe mitral is stenosis are not justified to have routine intervention in view of the fetal risk associated with cardiopulmonary bypass during pregnancy. Therapy must be individualized according to the risk of intervention at each institution and the gestational age of the patient	IIa	C
	Closed mitral valvotomy	IIb	C
	Open mitral reconstruction or replacement	IIa	C
2. Symptomatic severe aortic stenosis refractory to medical therapy for pulmonary edema or low output syndrome	Aortic valve replacement once fetal maturity in third trimester with fetal monitoring	I	B
	Percutaneous aortic valvotomy reserve for salvage situations where surgery is not possible	IIb	C

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SECTION IX: REOPERATIVE VALVULAR SURGERY

The focus of this section is to elaborate on the indications for reoperative valvular surgery and the surgical considerations required to maximize the safety of reoperative procedures (1-31).

The major challenge for the surgeon is related to the inability to control the optimal timing of reoperation (1). The surgeon has no control when the patient's clinical status is NYHA class III to IV under emergency circumstances. These circumstances can occur with thrombosed mechanical prostheses but should not occur with structural valve deterioration of bioprostheses. The surgeon should strive for a relative degree of control in the optimal timing of reoperation. This can be achieved by meticulous follow-up with more aggressive education of patients and medical advisors. Good risk patients can have reoperative procedures performed with early mortality no greater than the initial procedures. The early mortality for good risk elective procedures should not exceed 3%. The emergency procedures that result in high mortality are usually contributed to by ill-informed medical advisors.

The success of reoperative procedures is achieved by careful planning and error-free surgery. The reoperative procedure should be performed early in the disease process before LV function deteriorates (1-9). It has been recognized that untoward events in the cardiac surgery intensive care unit are a magnification of errors that occur in the operating room. The careful planning and conduct of reoperative procedures incorporates optimal myocardial protection and meticulous attention to operative detail.

Reoperative valve replacement is performed for several reasons: thrombosis of the prosthesis, periprosthetic leak, PVE and structural valve deterioration. Not all reoperations absolutely require rereplacement of the prostheses. Acute thrombosis may be treated by thrombectomy and periprosthetic leak by simple resuture of the area of dehiscence. Prosthetic valve endocarditis, structural valve deterioration and extensive periprosthetic leak nearly always require rereplacement. Reoperative valve surgery may involve procedures for previous reparative surgery, both for aortic and mitral valve reconstruction. The factors involved in reoperative surgery include ease of implantation, difficulty of surgery, the surgeon's technical ability and durability of the prosthesis. Patient acceptability is also an important factor in successful reoperative surgery.

INDICATIONS FOR SURGERY

Prosthetic valve endocarditis

Reoperative valvular surgery should be conducted in the presence of prosthetic endocarditis when there is prosthetic dysfunction and the risk of septic embolization. Unlike NVE, it is unlikely that prosthetic endocarditis can be resolved with medical management although there are circumstances when a bioprosthesis has been preserved. The latter is when the bacteremia is accompanied by vegetations on the leaflets of the bioprosthesis without involvement of the sewing ring.

Prosthesis thrombosis

Prosthesis thrombosis is primarily contributed to by inadequate anticoagulation. Prosthetic valve thrombosis may be obstructive or nonobstructive. Thrombus may accompany pannus formation, but pannus as a sole mechanism is infrequent. Thrombus usually originates in the prosthesis hinge mechanism; in the early phase after replacement, the thrombus can be related to suture ends. Prosthesis thrombosis is usually suspected by sudden hemodynamic impairment or an embolic event. Transesophageal echocardiography identifies thrombus on the prosthetic valve or within cardiac chambers and the accompanying partial preservation of disc excursion. Thrombolytic therapy may be successful under these circumstances in resolving the situation without significant cerebral or peripheral vascular embolization. Otherwise, if thrombus is long standing and well formed and there is a risk of thrombus (or of a healed vegetation) acting as a continuous source of fresh thrombus formation and potential embolization, then reoperation becomes necessary. The usual absolute indication for emergency surgery is cardiogenic shock or pulmonary edema; thrombolytic therapy in these circumstances for obstructive prosthetic valves may have an emergency role. Sometimes thrombectomy is sufficient and prosthesis replacement is not necessary. With the availability of transesophageal echocardiographic assessment and the assurance that the ventricular aspect of a mitral prosthesis is free of important thrombus, it is sometimes sufficient to clear thrombus from the left atrium. This lesser intervention can prove to be very satisfactorily curative without the additional risk of the much more extensive dissection required for prosthetic rereplacement.

Paravalvular leak or prosthesis dehiscence

In circumstances where there is a paravalvular leak resulting in hemolysis or progressive insufficiency of the prosthesis, reoperation may well be required. A lesson learned from the past is that, in the absence of adequate debridement of either aortic or mitral annular calcification, there tended to be a breakdown of the suture line over time with paravalvular leak dehiscence, hemolysis and the requirement for difficult prosthesis re-replacement.

Bioprosthetic structural failure

When a bioprosthesis begins to fail, it should be understood that the failure will be progressive and may accelerate. Preferentially, these patients should come for prosthesis re-replacement earlier rather than later when other factors are more favourable for a lower risk, successful surgical intervention. Too often, patients with failing bioprostheses are followed until they become acutely ill and therefore represent a much higher operative risk.

Pannus formation

One of the continuing reasons for prosthesis rereplacement is the development of pannus relative to the effective orifice of the prosthesis. This is particularly true of the Starr-Edwards aortic prosthesis (Edwards Lifesciences, USA) but can also be true of the more contemporary tilting disc or bileaflet prostheses. As the stenosis across the prosthesis begins to approach the significance of native valve stenosis, reoperation should be considered. In the case of aortic prosthetic stenosis, across a small prosthesis, pericardial patch enlargement of the LVOT may be necessary to accompany prosthesis rereplacement.

Prophylactic prosthesis rereplacement

In the presence of a mechanical prosthesis such as the welded outlet strut convex-concave disk Bjork-Shiley prosthesis, from the 1970s and the early 1980s, if the ongoing risk of outlet strut fracture is greater then 1% per year and the patient is in his or her 50s or younger and otherwise a good surgical candidate, then the long term prognosis is likely better served by elective explantation and rereplacement of that mitral prosthesis. With regard to this procedure, the World Panel recommends re-replacement when the 30-day mortality of the re-replacement is estimated by a skilled surgical team to be less than 3.5%. Another area for potential consideration of rereplacement of these Bjork-Shiley prostheses resides within the context of surgery required for other cardiac reasons.

It should always be remembered, however, that the addition of a mitral or aortic valve re-replacement to a coronary bypass procedure, or a mitral valve re-replacement to an aortic valve procedure, carries significant additional perioperative risk with respect to both morbidity and mortality. In the latter case, the replacement of the previous aortic prosthesis can make the mitral replacement less difficult and avoid periprosthetic complications.

Prosthesis replacement in conjunction with other cardiac procedures

If a bioprosthesis in a younger patient has been present for a few years and there is evidence of early failure, a strong argument can be made for re-replacement of that bioprosthesis at the time of necessary coronary surgery or other valve surgery, to avoid the higher risk of a third or multiple time intervention to replace that failing bioprosthesis at a later date.

SURGICAL RECONSIDERATIONS AT REOPERATIVE VALVULAR SURGERY (10-20,29-31)

Diagnostic assessment and surgical approaches

Preoperative assessment of the juxtaposition of the right ventricle, the aorta, the innominate vein to the table of the sternum and of the manubrium is very useful in planning surgical strategy for reoperative cardiac surgery. The distance between the heart and sternum should be assessed by lateral view of the chest radiograph or CT scan at 3 mm intervals from the suprasternal notch to the xiphoid. If there is concern about the lateral chest radiograph, a CT scan should be performed. When there appears to be satisfactory space behind the sternum and the manubrium, the usual sternotomy incision with an oscillating saw can be carried out without dramatic complication.

In reoperative mitral or tricuspid surgery where there is RV dilation and likelihood of distention of the right atrium, the right ventricle and the innominate vein and if there is not a clear plane defined with radiograph or CT scan, an alternative approach is necessary. The use of partial CPB with femoral-femoral or auxillary-femoral cannulation can very successfully decompress the right heart and the innominate vein to allow for much safer re-entry of the chest and a controlled situation in the event of entry of the right heart or the innominate vein. If there is a very real concern about the aorta itself and its placement relative to the sternum or the manubrium (as may be the situation with a reoperative Bentall procedure), another consideration is femoral-femoral or auxillary-femoral bypass and profound circulatory arrest before sternotomy. Without these precautionary arterial cannulation approaches, entry into the right heart, the innominate vein or the aorta can prove to be catastrophic and the outcome fatal.

Reoperative mitral surgery can be conducted by a right anterolateral fourth interspace thoracotomy but it is more difficult to mobilize the aorta safely, and to adequately cross-clamp the aorta and de-air the heart (30). The surgeon needs to adapt the surgery according to the patient's situation, the presence of coronary disease, and also the presence or absence of aortic regurgitation. This approach can be facilitated by double lumen endobronchial intubation and early right lung decompression. Repeat sternotomy is recommended for aortic valve exploration or repeat coronary artery bypass and mitral valve procedures, as well as for aortic regurgitation and accompanying chronic obstructive pulmonary disease.

The best strategy to avoid these re-entry complications is the surgical technique at the initial procedure. Where possible, it is appropriate and beneficial to approximate the tissue, the anterior mediastinum and the pericardium over the base of the heart and the great vessels, thereby protecting the innominate vein, the aorta, and often the right atrium and right ventricle. Meticulous hemostasis at the initial procedure will help to minimize the intensity of adhesions. Bovine pericardium or Gore-Tex (WL Gore & Associates Inc, USA) can be used to replace the pericardium; the pericardium should be washed well to remove glutaraldehyde. The bovine pericardium may be adherent or readily excised at reoperation. At the initial operation, the pericardium should be opened to the left side to allow closure of the normal pericardium under the sternum.

When coronary artery bypass surgery was completed previously, many surgeons brought the left internal thoracic artery to the left heart (usually the left anterior descending coronary artery) through a window created in the pericardial sac posterior to the plane of the sternum anterior to the plane of the phrenic nerve. In the event of reoperative surgery, the left internal thoracic artery was well removed from the plane of the sternum and medial to the upper lobe of the left lung. The same consideration should be applied when the right internal thoracic artery is used in continuity as a graft to the right coronary artery.

Procedural considerations (29-31)

External defibrillation paddles should be used for all reoperative procedures. This avoids the necessity for freeing the ventricles of adhesions. If there is short circuiting during defibrillation, the sternal retractor can be removed.

The approach to the heart is very important and the use of the oscillating saw rather than the reciprocal saw can make a major difference. Some surgeons have the previous sternal wires in place. The oscillating saw divides the sternum to the posterior table, starting at the manubrium and extending superiourly. The posterior table is divided by scissors facilitated by minimal traction and elevation. As previously stated, sternotomy requires minimal retrosternal dissection unless left-sided aortocoronary grafts are required. The aorta and right atrium are freed for cannulation, unless alternative groin or auxillary areas have been prepared before sternotomy for appropriate indications. The use of a cell saver is important for autotransfusion in reoperative surgery. The reoperative procedures take longer and require more dissection. The ventricles do not need to be freed of adhesions unless there is a necessity for left-sided coronary artery bypass grafts.

Adequate exposure is the key to successful reoperation. There must be adequate mobilization to visualize all aspects of the aortic root or the mitral annulus (or the tricuspid annulus). It is critically important to protect the myocardium, which can be achieved by the use of antegrade and retrograde hypothermic blood cardioplegia and systemic hypothermia to moderate levels. Myocardial protection is facilitated by avoidance of mechanical injury, avoidance of ventricular distension, maintenance of adequate perfusion pressure and balance of myocardial oxygen supply and demand. There is no rationale for 'short cuts' in not aiming for optimal cardioplegia. Retrograde back flow can be seen from the coronary ostia.

The standard approach to CPB in many centres is percutaneous femoral vein cannulation and direct ascending aorta cannulation. Superior vena caval cannulation is also done with the use of vacuum-assisted CPB. The optimal cardioplegic delivery in reoperative surgery is a combination of antegrade and retrograde techniques. In aortic regurgitation, retrograde is preferable. In the approach to the mitral valve, adequate mobilization is used. Complete dissection of the ventricular apex or the transseptal approach is used to facilitate mitral valve exposure. A very satisfactory approach to the mitral valve is the so-called anterior or transatrial approach through the right atrium, the interatrial septum and the roof of the left atrium. This approach requires less than complete mobilization of the left ventricle to visualize all the structures, the mitral annulus and the mitral apparatus. The approach allows reconstruction of the mitral annulus. It allows for reconstruction of the continuity between the mitral and aortic valves in the event that extensive reconstruction is required. The approach facilitates minimal traction on the tissues, as well as direct cannulation of the coronary sinus for retrograde cardioplegia delivery, especially for combined coronary artery bypass and valve rereplacement. The trans-septal approach is also optimal for prior AVR and the need for tricuspid annuloplasty. The standard approach to the mitral valve via the Sondergaard's groove can be used. This exposure for the mitral valve does not require sponges to displace the posterior wall to see the annulus; release of pericardial retention sutures facilitates exposure of the heart if fully mobilized.

As far as the aorta is concerned, good mobilization, access and visualization are also critically important. In removal of an aortic prosthesis or ascending aortic conduit (ie, allograft root), care must be taken to avoid damage to surrounding tissues or conducting bundle, membranous septum (LV/RV fistula), anterior mitral valve leaflet, posterior aortic annulus or coronary arterial ostia.

The valvular procedure must include aggressive and adequate debridement of all pre-existing annular tissue or pledgets and calcium. An aggressive approach to the debridement with generous reconstruction using bovine pericardium leads to very satisfactory results in reoperative valve surgery. In the same context, it is important to remember to be generous with the size and placement of the bovine pericardial patches so that they do not in and of themselves cause distraction, bleeding and disruption of tissues. A larger prosthesis than previous for aortic and mitral replacement should not be attempted; the annulus scar tissue must be removed and pericardial enlargement should be performed if necessary. Aortic sizes 21 to 25 mm and mitral sizes not less than 27 mm are optimal. Dehiscence can occur with a mitral prosthesis that is too small. The Maze procedure is usually not attempted for chronic atrial fibrillation in reoperative valvular surgery. The new alternative techniques, inclusive of radiofrequency and cryosurgery, could be used for chronic atrial fibrillation in reoperative mitral valve surgery.

There are other important aspects of a reoperative procedure. The heart is usually vented through the right superior pulmonary vein but may be vented through the pulmonary artery. There should be consideration to conduct tricuspid annuloplasty for any degree of tricuspid regurgitation. Prostheses should have a supra-annular sewing ring with noneverting pledgeted sutures (horizontal mattress). Noneverting sutures create less stress and torque on the tissues. Consideration should be given to resuspension of the papillary muscles in reoperative mitral valvular surgery. The avoidance of air embolism (intracoronary or systemic) can be facilitated by judicial use of CO_2 insufflation commenced before cardiotomy. Excessive intracardiac suction minimizes intracardiac air. The procedure should incorporate the proximal ascending aorta as the de-airing port with the heart beating, and lungs working with evacuation of air, before removal of the cross-clamp. If the procedure incorporates an aortotomy, the heart should be filled as the aortotomy is closed.

Stented bioprostheses and mechanical prostheses are excised by sharp dissection with removal of previous sutures and the prosthesis. Injury to the annulus is avoided by identifying the junction between the sewing ring and the atrioventricular junction or annulus. If this is not possible, the surgeon should err on the side of leaving portions of the sewing ring at the initial dissection.

A freehand or inclusion allograft cylinder may be more difficult to remove (15,27). Remnants of an allograft aortic wall may be extensively calcified and require great care in removal. Removal of the allograft should leave the aortic root in satisfactory condition for replacement with another allograft or a different prosthesis. The coronary buttons at the initial operations may be too small and create difficulty at the reoperation. It is possible to implant a valvular prosthesis subcoronary within the allograft. The aortic valve annulus will be smaller after an allograft. A stentless heterograft implanted initially in the subcoronary position can be explanted readily and easily because of light adherence of the xenograft to the host aortic sinus wall (10).

Special considerations are necessary for valvular procedures when coronary artery bypass procedures have been previously conducted (12,31). The re-entry considerations include the right ventricle, the vein graft to the right coronary artery, the innominate vein and the internal thoracic artery grafts. Focused surgical dissection is necessary when there are coronary bypass grafts. When an internal thoracic artery graft crosses the middle line, deflation of the lungs will support safe sternotomy. A Doppler probe can be used to identify patent internal thoracic grafts. The patent internal thoracic artery graft must be clamped and cardioplegia must be delivered retrogradely. Retrograde cardioplegia is recommended for repeat revascularization because antegrade cardioplegia can embolize atherosclerotic debris through old vein grafts. The decision to transect old vein grafts should be made on an individual basis. Antegrade cardioplegia should be delivered through reconstructed vein grafts. The safety of re-revascularization procedures with valvular reoperations is facilitated by elective timing.

Reoperative procedures should be conducted with the support of antifibrinolytic agents (aprotonin, tranxemic acid or amicar) to decrease perioperative blood loss. Precautions are recommended if there is borderline renal failure. Meticulous hemostasis is necessary in reoperative surgery. Low frequency electrocautery for lysis of adhesions is important to reduce capillary bleeding.

Reoperations for acute type A dissections may be required because of progressive enlargement of native aortic sinuses or aortic regurgitation, residual false lumen in the thoracoabdominal area causing aneurysms and mediastinal false aneurysm from graft infection, or glue necrosis from excessive amounts of the polymerizing agent of gelatin-resorcinol-formaldehyde (GRF)-glue (18). Biological glues have essentially replaced GRF-glue. These patients require aortic valve or aortic root replacement (17,18).

Composite graft replacements may present for reoperation due to annular abscess endocarditis. The LVOT must be reconstructed with an allograft incorporating the anterior leaflet of the mitral valve, or autologous or heterograft pericardium. The coronary button technique may cause difficulty in reoperations and extensions may be necessary with a segment of saphenous vein or synthetic graft. The risk of recurrent endocarditis is reduced by using an allograft.

The weaning from CPB may be prolonged after lengthy reoperative procedures. Adequate reperfusion and resting of the contracting myocardium on partial CPB may obviate the need for inotropic or chronotropic support. Atrioventricular pacing wires are part of any reoperative procedure. The use of IABP may be limited by aortic arteriosclerotic occlusive disease. The IABP may be inserted through the aortic arch. Transesophageal echocardiography should be standard for all reoperative procedures to confirm complete de-airing, assess quality of mitral valve repair and assess ventricular function.

The risk factors of reoperative surgery (1-9) are:

- increased age;
- left main coronary disease;
- CCS/NYHA class;
- smaller bioprosthesis in first operation;
- earlier year of operation;
- pulmonary artery hypertension;
- shorter interval to reoperation;
- multiple valve disease;
- greater LV dysfunction;
- acute onset bioprosthetic regurgitation;
- peripheral vascular disease;
- elevated preoperative creatinine;
- acquired coronary disease after first operation requiring revascularization;
- failure to use retrograde cardioplegia;
- emergency reoperation;
- acute aortic dissection;
- second to fifth reoperations;
- active endocarditis;
- female sex;
- intraoperative technical problems; and
- postoperative dialysis.

The principles and techniques of reoperative valvular surgery are of extreme importance because the necessity for reoperative surgery will only increase over future years. The challenges of reoperative surgery increase specifically with more than one reoperative procedure. Reoperation will remain a significant challenge unless the timing of reintervention can be optimized. The incidence of reoperation can be minimized by selection of prosthesis (mechanical versus biological) but the morbidity from a mechanical prosthesis may not outweigh the morbidity and reoperative risks from a biological prosthesis.

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SECTION X: PATHOLOGY OF PROSTHETIC HEART VALVES

The past 35 years have seen a dramatic change in the management of valvular heart disease (1-3). This was brought about by the development of prosthetic heart valves and total CPB, and their ongoing refinement. Over this time period, prosthetic heart valves also evolved, with improvement in the biological materials used as well as the development of less thrombogenic and more fatigue-resistant nonbiological materials, and of newer prostheses that have reduced pressure gradients. As a result, patients with chronic valvular disease, or even acute valvular disease, can look forward to enhanced long term survival, improved quality of life, and diminished symptoms following valve replacement surgery (4). Survival after multiple reparative episodes of surgery is now relatively common. Despite these important advances, the ideal heart valve prosthesis has not yet been designed. Limitations in prosthesis design and the resulting prosthesis-related complications have a significant impact on outcome after valve surgery (2,5).

While prosthesis-related complications are significant, the outcome of valve replacement surgery in any individual patient actually depends on four major factors (5-10):

1) Technical aspects of the surgical procedure;
2) Structural changes in the heart and lungs related to chronic valvular disease;
3) Comorbid conditions such as significant CAD;
4) Behaviour of the prosthetic heart valve and the nature of its interaction with its host.

In this section, only the last factor is considered as it relates to the outcome of heart valve replacement surgery. Specifically, the pathological processes and modes of failure common to the major prosthetic heart valves in contemporary use are described. An understanding of the morphological changes in heart valve prostheses removed at surgery or at autopsy, either associated with prosthesis dysfunction or normal valve function, is important because it can have an impact on current and future prosthesis design, as well as on patient management (5). For example, detailed examination of such prosthetic valves may provide insight into modes of prosthesis failure not appreciated during in vitro and preclinical tests in animals. Additionally, novel modes of failure may be identified in new or modified heart valve prostheses. Further, correlation of pathological findings with clinical imaging studies may enhance capability of clinical recognition of prosthesis dysfunction. Finally, it is hoped that an appreciation of the pathological processes and modes of failure in these valves will assist clinicians in the diagnosis, treatment and prevention of prosthesis-related complications. Before embarking on a description of the modes of failure and complications associated with prosthetic heart valves, a brief summary of the different heart valve prostheses used will be provided.

PROSTHETIC HEART VALVES

Prosthetic heart valves currently in use are categorized as either mechanical or tissue prosthetic heart valves (5,7-9,11,12). A wide variety of valve types, differing in concept, structure and components, has been developed over the years with a small number of them achieving widespread clinical use. Regardless of their specific structural configuration and make-up, both mechanical and tissue valves open and close passively in response to changes in pressure and flow.

Mechanical heart valves

Mechanical prosthetic heart valves are made of nonphysiological materials that may be metallic or synthetic such as teflon, pyrolytic carbon, titanium, silicone rubber, tungsten and graphite (5,7-9,11,12). Mechanical heart valves are comprised of a rigid but mobile flow occluder (or poppet), a cage or super structure that allows the occluder to float (ie, open and close) but restricts the range of its movement, a valve body or base, and a sewing ring cuff that allows valve prosthesis implantation.

Over the years, several major mechanical heart valve prosthesis designs have been used (11,13-15). These include caged ball, caged disk, tilting disk and bileaflet tilting disk valves. The caged ball and caged disk mechanical prostheses are rarely used today (in North America). Most prosthesis occluders are made of pyrolytic carbon or pyrolytic carbon coated disks, although the occluder in the Starr-Edward caged disk valve was made from cured silicone rubber. Pyrolytic carbon is an ideal material for rigid prostheses, having favourable mechanical properties such as high strength, fatigue resistance and excellent biocompatibility, as well as good thromboresistance. The super structure or cage for many contemporary mechanical valves is composed either of pyrolytic carbon, titanium or cobalt nickel alloy. In other valves, specifically the bileaflet tilting disk prostheses, the super structure is pyrolytic carbon coated over a metal or graphite substrate. Blood flows through mechanical valve prostheses by passing around the occluder. As a result, such valves are inherently obstructive to some degree and have localized areas of distal blood stasis. Currently, mechanical heart valve prostheses account for 60% to 70% of the prosthetic heart valves implanted worldwide (5,16) with bileaflet tilting disk prostheses accounting for the majority.

Tissue heart valves

Tissue heart valves, which are more flexible than mechanical heart valves, are typically comprised of three cusps and function similarly to a native valve (5,7-9,11,12,16). The cusps in tissue heart valves are of biological origin arising from animal or human sources. Tissue heart valves are, thus, either heterografts or xenografts (eg, porcine aortic valves or bovine pericardial tissue), homografts or allografts (eg, aortic or pulmonary valves obtained from human cadavers), or autografts (eg, the patient's own pulmonary valve, pericardium or fascia lata). Heterograft tissue valves are made from animal tissue, including porcine aortic valve or bovine pericardium, that has been fixed, usually in dilute gluteraldehyde, and mounted on a synthetic frame consisting of posts or struts. Such valves are commonly referred to as 'bioprosthetic heart valves'. As with mechanical heart valves, a fabric sewing ring surrounds the base of the tissue heart valve to hold sutures in order to secure the valve in place. Stentless heart valve prostheses are similar to the usual porcine aortic bioprosthesis except for the absence of a stent (16). The outer surface is covered in fabric with a fabric wrap around the proximal end to assist in securing the prosthesis in place (16). Homograft aortic or pulmonary valves (and associated portions of aortic or pulmonary root) obtained from human cadavers are cryopreserved and implanted directly in place without a synthetic frame.

MODES OF FAILURE AND PATHOLOGICAL CONSIDERATIONS

Complications, including mortality, arising in association with heart valve replacement surgery may occur early (within 30 days postoperatively) or late (more than 30 days postoperatively) after the procedure (7,17,18). The relative contribution of complications specifically attributable to heart valve prostheses differs significantly between the early and late postoperative periods.

Early postoperative complications

Early postoperative morbidity and mortality following heart valve replacement has diminished substantially in recent years, owing largely to improvements in surgical techniques, anesthesia and cardiac protection (7,9). Overall operative mortality ranges from 2% to 10% for aortic and mitral valve replacment and 5% to 10% for multiple valve operations (9,19). The risk of surgery varies considerably with the clinical details and the pathological features of each case (7,9). Patients with poor ventricular function are at especially high risk. Simultaneously performed procedures, such as coronary artery bypass grafting, only slightly increase operative risk (8,20,21).

In the early postoperative period, the majority of patients die of pre-existing cardiovascular disease or operative complications (7,8,17,18). Acute myocardial injury, including necrosis, occurs frequently and is a major cause of death in this setting. Of 279 cases studied at autopsy, myocardial injury was considered a cause of death in 24% (17). In these hearts, two patterns of myocardial necrosis were observed — coagulative necrosis and contraction band necrosis. The latter form of necrosis presumably results from severe global ischemia of the myocardium followed by reperfusion (8). Postoperative pump failure, in the absence of any myocardial necrosis, was also a frequent cause of death in these patients, accounting for approximately 30% of cases. The pump failure observed in these cases may be a reflection of postischemic myocardial dysfunction or myocardial stunning.

Removal of the diseased native valve and placement of sutures associated with the prosthetic heart valve can be associated with significant pathological consequences (8). For example, the bundle of His can be damaged by either deep dissection or suture placement resulting in complete heart block. The left circumflex coronary artery traverses the atrioventricular groove a very short distance away from the attachment of the mitral valve posterior leaflet. A deeply placed suture in this location can entrap the artery and lead to myocardial ischemia and necrosis. Further, a deeply placed anterior suture can tether or tear the left or noncoronary cusp of the aortic valve, leading to incompetence.

LV rupture or aneurysm formation can occur postoperatively at the level of the papillary muscles, the chordae tendinae, or in the mitral subannular region (22-25). Several possible mechanisms may account for this complication, including an excessively deep cut during removal of papillary muscle tissue, dissection of blood into the papillary muscle wound, impingement of the LV free wall by a prosthetic valve strut, intrinsic myocardial disease, or excessive wall tension arising from interruption of the continuity between papillary muscle and mitral annulus (8). Fortunately, the incidence of this complication has diminished with increased awareness, modification of procedures and use of instruments.

Very few early postoperative complications are directly attributable to the implanted prosthetic valve, and these account for 6% to 13% of early deaths (17,26,27). In the early postoperative period, prosthesis-related complications include thrombotic occlusion, thromboembolism, infective endocarditis, prosthesis disproportion and prosthesis dehiscence.

Late postoperative complications

The probability of survival five and 10 years following heart valve replacement is approximately 70% and 50%, respectively (6,28). The outcome in terms of long term survival is strongly correlated with overall LV functional status and the extent of CAD (3,29-31). Late mortality and morbidity result either from prosthesis-related complications or cardiac failure due to progressive myocardial degeneration (8) with prosthesis-associated complications (accounting for about 47% of late deaths) (17). Prosthesis-associated complications often lead to reoperation such that rereplacements currently account for 15% to 25% of all valve operations (5,32).

PROSTHETIC HEART VALVE-RELATED COMPLICATIONS

Complications associated with heart valve prostheses are important factors in determining long term prognosis following valve replacement surgery, resulting in reoperation, morbidity or death (5,8,14). Even though mechanical and tissue heart valve prostheses differ substantially in structure and are predisposed to different complications, the overall rate of problems is similar between the two valve types. Prosthesis-related complications are responsible for reoperation or death in about 50% to 60% of patients within 10 years of valve replacement surgery (4,5,8,14). Despite similar overall complication rates, the frequency and nature of specific valve-related complications vary with prosthesis type, site of implantation and patient factors (8). Four broad categories of heart valve prosthesis-related complications are recognized and include the following:

1) thromboembolic or hemorrhagic;

2) infection;

3) structural dysfunction; and

4) nonstructural dysfunction.

Thromboembolic or hemorrhagic complications

Thrombotic deposits may form on heart valve prostheses, a much more likely occurrence in mechanical heart valves whose nature renders them more thrombogenic than tissue valves (5,6,8,9,18). If thrombotic deposits occur, they can alter prosthesis function by interfering with occluder motion or obstructing the valve orifice. Additionally, these deposits may generate thromboemboli. Use of anticoagulants to prevent thrombus formation, which is essential in patients with mechanical heart valve prostheses, may lead to hemorrhagic complications. Together, complications related to thrombosis, thromboembolism and anticoagulant-associated hemorrhage are major causes of morbidity and mortality after heart valve replacement surgery.

Prosthetic heart valves in current use have thromboembolic rates of approximately 1% to 4% per patient per year (8). Interestingly, rates of thromboembolism are similar for mechanical and tissue valves when adequate levels of anticoagulation are used in patients with mechanical valves (5,6,8,28,33). Differences in rates of thromboembolic events do occur between the different types of mechanical heart valve prostheses (34). A greater risk of thromboembolism occurs in mechanical caged ball valves than in mechanical bileaflet or tilting disk valves. Additionally, there is a greater risk in valves implanted at the mitral compared with the aortic site. Age and significant coronary atherosclerosis have also been identified as significant risk factors for the development of thromboembolic complications (6).

Somewhat surprisingly, rates of hemorrhagic complications are not higher in all patients with mechanical heart valves than in those with tissue valves (6,33). Hemorrhage rates are higher in patients with mechanical valves in the aortic site compared with aortic tissue valves. By 15 years postoperatively, about 15% of patients with an aortic mechanical valve had a hemorrhagic event compared with 8% of aortic tissue valve patients (6). Rates of hemorrhage are similar for mechanical and tissue valves in the mitral location, with approximately 15% of patients with both types of valves having a hemorrhagic complication (6).

Infection

Prosthetic valve infective endocarditis is an uncommon but serious complication of heart valve replacement. Its occurrence ranges from 1% to 6% of all patients with prostheses (5,8,15). Rates of infection do not differ significantly between tissue and mechanical prostheses. However, the incidence of infective endocarditis in patients undergoing valve replacement for infective endocarditis is significantly higher than in those undergoing valve replacement for other indications (5,8,15).

Prosthetic valve endocarditis is classified as occurring early (within 60 days postoperatively) or late (more than 60 days postoperatively) (5,8,15,35). Early infection results from perioperative bacteremia from skin or wound infections, or contamination of prosthesis and other intravascular devices. As such, the organisms reflect the normal skin flora, including *Staphylococcus epidermidis*, *S aureus*, Gram-negative bacteria, diptheroids and fungi (5,15). Late PVE, which results from hematogenous seeding, is commonly caused by organisms that also cause NVE, predominantly streptococci (5,15). The incidence of late PVE is slightly greater for tissue valves and for valves implanted at the aortic site (35). In approximately 10% to 15% of cases, no organism can be identified as the causative agent (5,15).

Because the synthetic materials used in mechanical valves do not readily support growth of microorganisms, infection of mechanical prostheses is generally localized to the tissue-prosthesis interface at the sewing ring, where destructive changes in tissue may lead to the formation of a ‘ring abscess’ (5,8,15). In tissue valves, infection may be localized in the vicinity of the sewing ring. However, the cusps may also be a focus of infection. The complications associated with PVE are variable and numerous (5,8). They include embolism of infected material, congestive heart failure secondary to mechanical obstruction or regurgitation due to large vegetations, or ring abscess formation that may result in valvular dehiscence, paravalvular leaks or heart block, arising as a result of damage to the conduction system. Mortality due to PVE is high, ranging from 30% to 80% for early infection and from 20% to 40% for late endocarditis (15).

Structural dysfunction

Structural dysfunction, which occurs as a result of degradation or degeneration of materials used in the manufacture of these devices, is an important cause of reoperation or prosthesis-related death in patients with mechanical and tissue prosthetic heart valves (5,6,8,15,28). Structural dysfunction occurs more commonly with tissue valves than with contemporary mechanical valves (5,6,8,15,28). The rate at which degenerative changes occur and the specific nature of the degenerative changes varies significantly with prosthesis type and location.

Mechanical prosthetic heart valves

In general, structural dysfunction occurs rarely in mechanical prosthetic heart valves (5,6,8,14,15,18,28). When present, such structural dysfunction has occurred in a variety of the materials used in mechanical prostheses. Silicone elastomeric ball occluders of early generation caged ball mechanical valves absorbed lipids from the blood and slowly developed swelling, distortion, cracking, embolization of occluder material and abnormal movement of the occluder, referred to as ball variance (5,8,36,37). Changes in elastomer fabrication largely eliminated lipid insudation-related ball variance, such that structural dysfunction was minimized in these mechanical valves.

Contemporary tilting and bileaflet tilting disk valves have very favourable durability (5,8,14,18). The excellent durability is a result of the presence of pyrolytic carbon coated occluders with or without coated cage components. However, fracture of metallic or carbon components of mechanical valves does occur rarely (8,14,18). For example, structural dysfunction of the Bjork-Shiley (Shiley Inc, USA) 60° and 70° convexo-concave mechanical heart valve prosthesis occurred with relatively high frequency (5,8,14,18,38-40). In these valves, metal fatigue led to fracture of the welded (smaller) outer strut with resultant separation from the valve and escape of the occluder. Not surprisingly, strut fracture is accompanied by a high mortality rate, with approximately two-thirds of such cases having a fatal outcome (5). The incidence of fracture in these prostheses varies with size and valve design with fracture incidence at five years estimated to be 2.2% for the 23 mm aortic 60° valve and 8.3% for the 29 to 31 mm mitral 70° valve (38).

Fracture of the carbon component in a small number of mechanical valves, including the Edwards-Duromedics (Edwards Lifesciences, USA) and St Jude Medical (St Jude Medical Inc, USA) bileaflet tilting disk valves, has also been reported (41-43). Despite the apparently excellent durability of contemporary mechanical heart valve prostheses, continued surveillance is necessary with critical analysis of potential regions of material wear and fatigue, such as pivot or hinge points in tilting disk mechanical valves, to identify any problems in the future.

Bioprosthetic heart valves

Primary tissue failure is the major cause of dysfunction of typical bioprosthetic porcine aortic valves (5,8,16). The rate of bioprosthetic valve failure increases over time, particularly after the initial four to five years after implantation. At 10 years postimplantation, 20% to 40% of porcine aortic valves implanted in either aortic or mitral sites require replacement for primary tissue failure (3,5,8,15,16,44). Up to 50% of such valves fail after 10 to 15 years. While differences in durability are not readily apparent between the two most commonly used porcine aortic valve bioprostheses (5,8,16), differences in rates of failure between aortic Hancock (Medtronic Inc, USA) and Carpentier-Edwards (Edwards Lifesciences, USA) porcine valves have been reported (3,44,45).

Calcification, cuspal tears or both are the most common manifestations of tissue failure in bioprosthetic porcine aortic valves (5,8,16,44,46-53). Regurgitation produced by cuspal tears due to calcification is the most common clinicopathological mode of valve failure. Calcific stenosis and regurgitation due to cuspal tears or perforations unrelated to calcification are less common modes of failure.

Calcification generally predominates at the commissural and basal regions of the cusps, locations at which the most intense mechanical deformation occurs during cuspal motion (5,8,16). The calcific deposits in these areas are visible as nodular yellow-white or grey-white masses, which often ulcerate through the cuspal tissue or show the presence of thin layers of thrombus on their surface (54,55). Microscopically, calcification predominates in the spongiosa of the valve cusps (56). The calcific deposits occur in relation to connective tissue cells or collagen in the valve cusps (27,57).

Prosthesis failure in general, and that due to calcification specifically, is influenced by the age of the patient at the time of implantation (16,27,57-61). Calcification and prosthesis failure are accelerated in younger patients, such that up to approximately 90% of left-sided valves implanted in children fail within six years of implantation (62). Young adults, particularly those aged less than 40 years, also show accelerated rates of calcification and failure (8,58,59). Importantly, other factors associated with altered calcium metabolism, such as chronic renal failure and parathyroid disease, may accelerate prosthesis failure with calcification (16).

Cuspal tears or perforations unrelated to calcification (or endocarditis) are likely the result of direct mechanical damage to the collagenous structure of the valves (53-55,63). Degeneration of collagen has been observed using high resolution imaging methodologies such as scanning electron microscopy (63). Such degenerative changes may occur at anytime postimplantation and appear more frequently in valves in the mitral than in the aortic site (54). The latter finding is presumably due to the higher closing pressures to which mitral site bioprostheses are subjected (16). Detachment of one or more commissural regions from their respective stent posts has also been described as a form of prosthesis failure. This abnormality typically occurs in second generation Carpentier-Edwards porcine bioprostheses in the mitral location and may occur in the absence of significant calcification or infection (64).

Stentless bioprosthetic porcine aortic valves, designed for use in the aortic site, have only been used for a relatively short period of time (16,65-68). At the current time, these prosthetic valves have shown minimal cuspal calcification or tissue degeneration for periods up to eight years following implantation.

As with bioprosthetic porcine valves, bioprosthetic heart valves made from bovine pericardium develop both calcific and noncalcific tissue failure (5,8,16). The first generation of pericardial bioprostheses, including Ionescu-Shiley (Shiley Inc, USA), Mitroflow (CarboMedics, Canada) and Hancock valves, had excellent hemodynamics but failed fairly rapidly after implantation (16,44,69-72). However, the second generation of bovine pericaridal prostheses, such as the Carpentier-Edwards pericardial valve, have increased durability compared with first generation pericardial valves (3,44). In fact, these bioprostheses appear to give results comparable with, and possibly better than, porcine bioprostheses (73).

Other tissue valves

Cryopreserved human homograft (or allograft) aortic valves have excellent hemodynamics and a low propensity to thromboembolic complications (16,57). These valves have equivalent or slightly better durability than contemporary bioprosthetic porcine valves with valve survival rates of approximately 50% to 90% at 10 to 15 years (74,75). However, progressive degeneration, similar to that seen in other tissue valves, limits long term durability (74-77). The pathology of pulmonary autograft replacement of the aortic valve (the so-called Ross procedure) has not yet been reported in detail. In the cases observed, the valve cusps reportedly retain normal architecture and staining quality of cells and interstitial tissues (57).

Nonstructural dysfunction

Paravalvular leaks

Paravalvular leaks are most often caused by infective endocarditis (78). However, a paravalvular leak may also occur as a result of suture knot failure, inadequate placement of sutures, separation of sutures from an annulus that is heavily calcified or myxomatous, or healing-induced tissue retraction (5,16). Patients with paravalvular leaks may be asymptomatic if the leakage is mild to moderate. In some cases, paravalvular leaks cause significant hemolysis and, when severe, can cause heart failure (5,16). Importantly, paravalvular leaks also increase the risk of developing endocarditis (16).

Hemolysis

Hemolysis was common with earlier generation heart valve prostheses, especially with mechanical valves (5,8,16). Hemolysis was severe enough in certain cases to cause hemolytic anemia. In general, normally functioning tissue valves and contemporary mechanical valves rarely cause clinically significant hemolysis. Severe hemolysis leading to anemia can occur in prosthetic valves as a result of a paravalvular leak, structural valve dysfunction or valvular thrombosis.

Prosthesis disproportion

As large a prosthetic heart valve as possible is used to minimize the transvalvular pressure gradient (5,8). Occasionally, however, a prosthetic heart valve is used that is too large for the anatomic site of implantation, a situation referred to as prosthesis disproportion. Such overly large valves may not function effectively, may lead to damage to surrounding structures or may even result in obstruction (22).

Prosthetic valve dysfunction due to fibrous tissue overgrowth or other extrinsic factors

Factors extrinsic to the valve prosthesis may interfere with its function, leading to stenosis or incompetence of an otherwise properly selected and sized prosthetic valve (5,8,16). For example, overgrowth of fibrous tissue onto the valve prosthesis may progressively narrow the valve orifice or stiffen the valve cusps to cause stenosis (79,80). In addition, the fibrous tissue may prevent complete excursion of valve occluder(s) or cusps to cause valvular stenosis or regurgitation. Valve occluder or cuspal motion may be interfered with by a variety of extrinsic factors other than fibrous tissue overgrowth, including a large mitral annular calcific mass, septal hypertrophy, large remnants of native valves or long sutures (46,54,81-85). Sutures looped around stent posts may also restrict cuspal motion in tissue valves (46). Furthermore, suture ends may perforate prosthetic valve cusps causing incompetence of tissue valves (46,86,87).

PATHOLOGICAL EVALUATION OF HEART VALVE PROSTHESES

Detailed analysis of surgically explanted prostheses and those seen at autopsy is critical if progress is to be maintained in the improvement of existing prostheses and the development of newer prosthetic heart valves. Increasing the number of autopsies performed on cardiovascular patients who die is critical if progress in valve prosthesis technology is to be maintained. It is equally, if not even more, important that explanted heart valve prostheses be examined in detail by individuals with expertise and interest in this area. Development of a central national registry of all heart valve prostheses would help coordinate nationwide collection of data and create a data bank for retrospective and prospective studies. In any pathological examination of cardiovascular tissue, an established protocol is important, so critical items in the analysis are not missed. One such protocol for the pathological analysis of prosthetic heart valves is provided (see section XV). Similar protocols developed by others have been published in the past (5,8).

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SECTION XI: ECHOCARDIOGRAPHIC GUIDELINES

Echocardiography is the method that provides the most complete and specific information with regard to the nature and severity of valvular disease (1-5). Echocardiography is an important adjuvant to the clinical evaluation of the patient by providing more specific and quantitative information. The clinical evaluation, inclusive of a complete history, physical examination and assessment of the NYHA functional class, will provide information with regard to the nature and severity of valvular lesions. Similar considerations apply to the electrocardiogram and chest radiograph which, in addition to orienting towards hypertrophy or prior infarction, may provide additional information with regard to the presence of arrhythmias or active ischemia. The information provided by echocardiographic examination may orient the surgeon towards the type of operation to be performed in a particular situation, specifically with regard to reconstruction or replacement for chronic mitral regurgitation.

A complete echocardiographic examination should include thorough assessment of cardiac structure and function. This should include M-mode, high quality two-dimensional images, and qualitative and quantitative Doppler assessment. Measurements of aortic root, left atrium, left ventricle, right ventricle, LV wall thickness, as well as evaluation of regional LV function and quantitation of global LV systolic function should be performed. Accurate and precise description of valve morphology is essential. This should include characterization of leaflet thickness, mobility, calcification, annular characteristics and subvalvular disease for the atrioventricular valves. Specific assessment should include not only the semiquantitation or quantitation of valvular stenosis and regurgitation, but also a clear description of the echocardiographic mechanism responsible for the valvular abnormality.

The severity of stenotic lesions is characterised from Doppler-derived determinations of transvalvular peak and mean gradients, based on the modified Bernoulli equation and calculations of the effective orifice area based on the continuity equation (and/or pressure half-time method in the case of mitral stenosis). Echocardiographic and Doppler techniques are needed to assess the severity of valvular regurgitation and remodelling of the cardiac chambers in response to the volume overload state (5). The duration (acute or chronic) and severity of valvular regurgitation are among the important changes in the adaptive remodelling. Chronic regurgitation is usually accompanied with increase in size and hypertrophy of cardiac chambers but acute onset may not result in remodelling. Regurgitant lesions are graded from one to four (+) based on the integration of a variety of measurements including cavity dimensions, mapping of colour flow Doppler, determination of regurgitant fraction and estimations of retrograde flows in the aorta, pulmonary or hepatic veins. To interpret results, the clinician should be aware of the pitfalls inherent in each of those measurements and should strive to obtain a concordance between the different measurements reflecting the same phenomenon. Another important aspect to consider is the comparison with previous examinations, to determine if the situation is stable or has deteriorated.

Transesophageal echocardiography (TEE) may be used to supplement the information provided by TTE, particularly when the latter is deemed unsatisfactory or incomplete (6-8). Particular situations include planimetry of the AVA in aortic stenosis (9-10) and evaluation of the mitral valve morphology and function when mitral valve reconstruction is contemplated. Some studies have advocated planimetry of the stenotic aortic valve using TTE, but reverberation and artefacts make two-dimensional measurement difficult, especially when assessment of the effective valve area is more important. Epicardial echocardiography may also be used in the operating room to evaluate the results of mitral valve reconstruction or of the insertion of a stentless substitute, whether it is autograft, allograft or heterograft. In such cases, it is recommended that the examination be performed by an experienced cardiologist or anesthesiologist, trained in echocardiography, familiar with the evaluation of valvular heart disease by Doppler echocardiography.

Cardiac catheterization is performed mainly to assess the coronary circulation in patients deemed at risk of CAD (11). Cardiac catheterization or magnetic resonance imaging (12-15) may also be performed to confirm and clarify the diagnosis in patients where there are discrepancies between clinical and echocardiographic data, or when the echocardiogram is not conclusive because of poor quality or inconsistencies between the different measurements.

Aortic stenosis

Two-dimensional and Doppler echocardiography are extremely important and useful for assessment of aortic stenosis. Aortic valve peak instantaneous pressure gradient, mean pressure gradient and valve area may be determined by Doppler interrogation of the aortic valve. The peak instantaneous pressure gradient between the left ventricle and the aorta can be measured by applying the modified Bernoulli equation:

$$\text{pressure gradient} = 4 \times (\text{velocity})^2$$

to the continuous-wave Doppler maximum velocity signal across the aortic valve (V_{AS}) (15,16). The Bernoulli equation should be corrected for the prestenotic velocity (LVOT velocity, V_{LVOT}) in patients with V_{LVOT} greater than 1.5 m/s ($P_{max} = 4 \times [V_{AS}^2 - V_{LVOT}^2]$). The mean pressure gradient can be calculated by averaging the instantaneous pressure gradients throughout ejection (15,16). In the elderly with dynamic muscular subaortic obstruction, the modified Bernoulli equation cannot be applied to the aortic velocity jet because the proximal velocity is not laminar.

The calculation of AVA should be performed in conjunction with measurement of the pressure gradient for determining the severity of aortic stenosis. The AVA can be calculated using the continuity principle in which flow (stroke volume) through the LVOT is equated to flow (stroke volume) through the aortic valve (17,18). Flow is measured by the product of (area × velocity time integral):

$$AVA=(LVOT_{diameter}{}^2 \times 0.785 \times VTI_{LVOT})/VTI_{AS}$$

where VTI_{LVOT} and VTI_{AS} are the velocity time integrals in the LVOT and across the aortic valve, respectively.

Two-dimensional echocardiography accurately detects the presence and etiological mechanism of aortic stenosis. However, the severity of aortic stenosis, in many patients, may be incorrectly estimated by transthoracic two-dimensional echocardiography. Valvular calcification may shadow LM and measurements of AVA by transthoracic planimetry have been unreliable. Multiplane TEE has provided better accuracy (9,10).

The severity of aortic stenosis is usually graded by Doppler echocardiography or cardiac catheterization as mild, moderate or severe (16-19). Transvalvular pressure gradients may be used to grade aortic stenosis severity in patients with normal LV function and cardiac output, and in the absence of aortic regurgitation. In general, mean transvalvular pressure gradients greater than 50 mmHg represent severe aortic stenosis, while gradients less than 25 mmHg suggest mild aortic stenosis. However, it is important to recognize that transvalvular pressure gradients are proportional to the square of transvalvular flow. Thus, transvalvular pressure gradients may overestimate the severity of aortic stenosis in the presence of hyperdynamic states or aortic regurgitation, and underestimate the severity of aortic stenosis in low flow states as with significant dysfunction (20,21). In these conditions, it is imperative to calculate AVA. In general, severe aortic stenosis has been defined as a valve area of 0.75 to 1.0 cm^2 or less, because flow is not usually restricted until an orifice is reduced to 25% of its original size (normal AVA is 3.0 to 4.0 cm^2). The normal valve area in small people may be less than 3.0 cm^2. With this orifice reduction, small incremental changes in orifice area lead to large incremental increases in transvalvular pressure gradient. Mild aortic stenosis has generally been defined as an AVA greater than 1.2 to 1.5 cm^2.

For the purpose of this consensus document, AVA less than 1.0 cm^2 is indicative of severe aortic stenosis. This is based on the observation that the vast majority of patients with symptomatic aortic stenosis have an AVA of less than 1.0 cm^2, and a lower 'cut-off' value may lead to a significant number of symptomatic patients being classified as having nonsevere aortic stenosis (22). It is important to recognize that the absolute valve area may not be an ideal index of aortic stenosis severity in patients of large or small body size. In large patients, valve areas greater than 1.0 cm^2 may represent severe aortic stenosis while valve areas less than or equal to 1.0 cm^2 may be adequate in small patients. Indexing AVA to body surface area may aid in the assessment of these patients. In this regard, mild aortic stenosis is defined as a valve area greater than 1.5 cm^2 (greater than 0.9 cm^2/m^2), moderate aortic stenosis as 1.0 to 1.5 cm^2 (0.6 to 0.9 cm^2/m^2) and severe aortic stenosis as less than 1.0 cm^2 (less than 0.6 cm^2/m^2) (23). In the absence of a high subvalvular velocity, severe stenosis is determined by a peak velocity greater than 4.5 m/s or a mean gradient greater than 50 mmHg. An additional criterion of severe stenosis a V_{LVOT}/V_{AS} less than or equal to 0.25.

Cardiac catheterization with measurement of transvalvular pressure gradients and AVA by the Gorlin equation (24) is rarely necessary to assess aortic stenosis severity and should be reserved for cases in which there is a discrepancy between the severity in clinical and echocardiographic findings, and surgical intervention is contemplated. Coronary angiography is recommended in all patients older than 35 years before surgery, because up to 50% may have coexisting CAD (25,26). Coronary angiography may not be required in young patients (less than 35 years) who have no risk factors for CAD.

One difficult problem is the patient with low output/low gradient severe aortic stenosis, in whom the calculated AVA does not correspond to the mean pressure gradient. The small calculated AVA may be due to critical end-stage aortic stenosis or alternatively to a calcified valve with mild stenosis where valve opening is limited due to poor myocardial contractility and low transvalvular flow (pseudosevere aortic stenosis) (27). Interventions to normalize cardiac output with dobutamine may distinguish the two entities (28-31). Normalization of cardiac output with a resultant mean pressure gradient greater than 30 mmHg is suggestive of severe aortic stenosis while gradients less than 30 mmHg suggest mild stenosis. Additionally, severe aortic stenosis is likely not present if AVA increases to greater than 1.0 cm^2 to 1.2 cm^2 with dobutamine infusion. If the cardiac output does not change and the mean pressure gradient is less than 30 mmHg, there is diminished myocardial reserve.

The role of exercise testing in patients with aortic stenosis has evolved and may become an important method for risk assessment in asymptomatic adult patients with significant aortic stenosis (32-35). The exercise echocardiogram can identify a silent state of LV dysfunction, impaired exercise tolerance, presence of symptoms, inappropriate exercise blood pressure response, or drop in exercise blood pressure up to 10 mmHg, bradycardia, arrhythmias, conduction disturbances and an exercise decrease in stroke volume or cardiac output (26). Exercise testing can be included in the decision-making process for surgery and during clinical follow-up.

Mitral stenosis

The hemodynamic severity of mitral valve obstruction should be assessed with Doppler echocardiography. Parameters to be measured include the resting mean transmitral gradient (MG), MVA and PAP. MG is accurately and reproducibly measured from the continuous wave Doppler signal across the mitral valve with the modified Bernoulli equation (36). MVA can be noninvasively measured by either the diastolic pressure half-time method, two-dimensional orifice planimetry or the continuity equation (37,38).

The normal MVA is 4.0 to 5.0 cm^2. Patients with an MVA greater than 2.5 cm^2 are generally asymptomatic both at rest and with exercise. When the MVA is between 1.5 to 2.5 cm^2, symptoms, usually dyspnea, may occur with increased transmitral flow (eg, exercise, emotional stress, infection, pregnancy) or a decreased diastolic filling period (eg, uncontrolled atrial fibrillation). Accordingly, mild mitral stenosis is defined as an MVA of 1.5 to 2.5 cm^2 and mean gradient at rest less than 5 mmHg. Moderate and severe mitral stenosis are defined as MVA 1.0 to 1.5 cm^2 and less than 1.0 cm^2, respectively (39). A diastolic pressure half-time of greater than 220 msec determined from the transmitral flow velocity curve obtained from Doppler echocardiography suggests severe mitral stenosis.

The MVA can be determined by the PISA method. The measurement is based on calculation of volumetric flow through the mitral valve from colour flow images of the convergence of flow proximal to the stenotic valve (40,41).

Doppler echocardiography should be used to determine PAP, a measure of the hemodynamic consequence of obstruction to LV inflow. The PAP is determined by applying the 'simplified' Bernoulli equation to the peak velocity of the tricuspid regurgitant jet obtained by continuous wave Doppler echocardiography. This yields the systolic RV to RA pressure gradient. An estimate of the RA pressure, derived from the respiratory response of the inferior vena cava on subcostal M-mode or two-dimensional imaging, is then added to this pressure gradient to obtain an estimate of the systolic PAP.

Percutaneous mitral commissurotomy (or balloon valvuloplasty) is a frequent initial therapeutic option for patients with mitral stenosis. The underlying mitral valve morphology is the most important factor in determining outcome, acute complications and rate of recurrent stenosis on follow-up after PMC. Accordingly, an echocardiographic scoring system has been developed to assess suitability for, and predict outcome of, PMC. The morphological appearance of the mitral valve apparatus is assessed by two-dimensional echocardiography, including leaflet thickness and mobility, commissural calcification and degree of subvalvular fusion (42). Each of these parameters is subjectively scored from one (least severe) to four (most severe) and a total score out of 16 is reported. Patients with a mitral valve score of eight or less and no more than mild mitral regurgitation have been shown to have the best results from PMC.

A TEE should invariably be performed immediately before PMC by an experienced cardiologist. The role of TEE in PMC is to exclude a thrombus in the left atrium which would lead to a change in patient management, including PMC delay or cancellation. In selected cases where a TTE provides suboptimal information, a TEE can also be useful to evaluate mitral valve morphology and hemodynamics (43-45).

There are conditions where the severity of symptoms are out of proportion to hemodynamic measurements and these provide challenges in diagnosis. Symptoms disproportionate to the degree of measured mitral stenosis can be evaluated by exercise echocardiography.

Aortic regurgitation

Echocardiography allows for the diagnosis and semiquantitation of aortic regurgitation severity, in addition to providing a method for serial assessment of regurgitation severity, LV chamber size and systolic function. The etiology of the regurgitation can usually be determined from two-dimensional echocardiography by assessing the valve morphology and aortic root. LV chamber size and systolic function may be measured by M-mode (28) and two-dimensional images (46).

Accurate assessment of aortic regurgitation severity can be difficult and requires a comprehensive evaluation of several Doppler parameters because no single measure provides an entirely accurate quantitative assessment. Semiquantitation of aortic regurgitation severity may be obtained by assessing the colour flow jet area as a ratio of the LVOT area, or the colour flow jet height as a ratio of the LVOT height. While the 'cut-off' values for the various grades of regurgitation vary between investigators (47), in general, severe aortic regurgitation is associated with a colour flow jet area to LVOT area ratio greater than 60%, or a jet height to LVOT height ratio greater than 65% (48-50). Nonsevere aortic regurgitation is associated with colour flow jet area to LVOT area ratios less than 20% and jet height to LVOT height ratios less than 45%, respectively (48-50). A four grade scale using either the ratio of jet height to LVOT height or jet area to LVOT area has been proposed for the assessment of aortic regurgitation severity: Grade IV is a jet greater than 65% of LVOT height or greater than 60% of LVOT area; Grade III is a jet 46 to 64% of LVOT height or 21% to 59% of LVOT area; Grade II is a jet 25 to 45% of LVOT height or 5 to 20% of LVOT area; and Grade I is a jet <25% of LVOT height or <5% of LVOT area. The slope or pressure half-time of the continuous wave Doppler regurgitant jet also relates to the regurgitant severity because it provides a measure of the diastolic aortoventricular gradient. Pressure half-times less than 250 m/s almost always represent severe regurgitation (50-52). The accuracy of the pressure half-time of the continuous wave Doppler signal in reflecting the grade of aortic regurgitation is dependent on left ventricular end-diastolic pressure (LVEDP) and LV impairment from any cause. Rapid equilibration of LV and aortic pressure may also result in premature diastolic closure of the mitral valve, which may be detected on M-mode recordings of the mitral valve. Fluttering of the anterior mitral valve leaflet confirms the presence of aortic regurgitation but does not provide any assessment of severity. The presence of holodiastolic flow reversal in the abdominal aorta with the absence of a patent ductus arteriosus or arteriovenous shunt has been reported to have a high sensitivity and specificity for severe aortic regurgitation (50,53). Aortic regurgitant volumes and fractions may be calculated from LV and mitral valve annulus stroke volumes, thus allowing quantitative assessment of aortic regurgitation severity (54,55). Regurgitant volumes greater than 60 mL/beat and regurgitant fractions greater than 50% have been associated with severe aortic regurgitation. However, these measurements are technically difficult and should not be employed in the assessment of aortic regurgitation severity until they have been validated in individual laboratories. Newer Doppler measures of aortic regurgitation severity using the effective regurgitant orifice area (56-58) or vena contracta colour flow imaging (59-61) provide promise in the assessment of aortic regurgitation severity. Vena contracta width below 5 mm corresponds to nonsevere aortic regurgitation and above 7 mm corresponds to severe aortic regurgitation. These parameters, determined by quantitative pulsed Doppler or PISA (proximal isovelocity surface area) or flow convergence, also provide for a four grade scale using regurgitant volume (mL/beat), regurgitant fraction (%) and effective regurgitant orifice area (cm^2). Grade IV is an R Vol≥60, RF≥50 and EROA≥0.40; Grade III is a R Vol 45-59, RF 40-49 and EROA 0.30-0.39; Grade II is a R Vol 30-44, RF 30-39 and EROA 0.20-0.29; and Grade I is a R Vol<30, RF<30 and EROA<0.20. The quantitative parameters of aortic regurgitation severity (four grade scales) facilitate grading as mild, moderate and severe with moderate subdivided as mild-to-moderate and moderate-to-severe.

Radionuclide angiography may be useful in the initial and serial assessment of LV function when this information cannot be obtained from echocardiography. Additionally, radionuclide angiography is warranted when the echocardiogram is suggestive, but not conclusive, for decreasing or deteriorating LV function. The routine use of radionuclide angiography in addition to echocardiography to assess LV function are not warranted. Exercise ejection fraction and the change in ejection fraction from rest relate to the degree of ventricular dilation and have not been shown to provide independent prognostic information beyond echocardiographic LV dimensions (62).

Cardiac catheterization is not required in patients with aortic regurgitation unless there is a discrepancy between clinical and echocardiographic assessment of regurgitation severity. Aortic regurgitation severity may be assessed on root angiography and considered severe when there is complete opacification of the left ventricle with a density greater than, or equal to, the density of the aortic root and persistence of the contrast after a single beat (63). Coronary angiography is recommended in patients being considered for surgical intervention if they have angina, LV dysfunction, a history of or risk factors for CAD (including age greater than 35 years).

Mitral regurgitation

The correct method to measure mitral regurgitation severity and the exact amount of mitral regurgitation requiring monitoring and therapeutic intervention is unknown. Current echocardiographic methods are predominantly Doppler based. It is essential, however, to consider the entire echocardiographic picture including chamber sizes, ventricular function, the structure of the mitral valve, as well as temporal changes in these measurements, to provide the most comprehensive echocardiographic information to the clinician to determine the need for and timing of therapy in mitral regurgitation (5,64-67).

Studies indicate that symptoms of LV dysfunction occur when the regurgitant fraction (mitral regurgitation volume/total LV stroke volume) exceeds 40% to 50% (68-70). The categorization of mitral regurgitation severity is proposed in Table 66.

This classification assumes the patient is in a stable and representative state with regard to afterload, preload and contractility. Using this classification, trace or mild mitral regurgitation, with a structurally normal mitral valve, may represent normal variants in subjects without valvular dysfunction. Patients with moderate and severe mitral regurgitation warrant consideration of surgical therapy, with the understanding that patients with moderate mitral regurgitation may be better served with nonoperative therapy or ongoing observation.

Mitral regurgitation relates to deficiency in leaflet free-edge apposition and effective coaptation. The deficiency results from alteration of the three-dimensional geometry of the valve and its attachments and the relation of the leaflets to the flow across the valve. The organic causes are mitral valve prolapse, systolic anterior motion (SAM) of the anterior leaflet, ruptured or elongated chordae and papillary muscle rupture. MVP and SAM are both due to excessive superior motions of the mitral leaflets. Ischemic or functional regurgitation is due to papillary muscle displacement, restricting the ability of the leaflets to close at the level of the mitral annulus. The mechanism here is decreased closing force or increased leaflet tethering.

The severity of mitral regurgitation can be assessed by several parameters using echocardiography:

Colour flow mapping: The regurgitant jet area is used as an absolute dimension or normalised for LA size as an area ratio to determine the degree of mitral regurgitation. The ease and familiarity of this technique has lead to persistent reliance on the method. The colour flow jet area usually tends to be larger by TEE compared with TTE for a given degree of regurgitation. Accordingly, thresholds for semiquantitation of mitral regurgitation severity differ between the two echocardiographic approaches. With TTE, trace mitral regurgitation corresponds to a maximum jet area (aliased and nonaliased contiguous flow) from any acoustic window of less than 2 cm^2 (less than 10% of LA area), mild mitral regurgitation corresponds to 2 to 4 cm^2 (10% to 20% of LA area), moderate mitral regurgitation corresponds to 4 to 8 cm^2 (20% to 40 % of jet area), and severe mitral regurgitation corresponds to greater than 10 cm^2 (greater than 40% of LA area) (71,72). However, with TEE, trace mitral regurgitation corresponds to a maximum jet area (aliased flow only) from any acoustic window of less than 1 cm^2 (less than 5% of LA area), mild mitral regurgitation corresponds to 1 to 3 cm^2 (5% to 15% of LA area), moderate mitral regurgitation corresponds to 3 to 6 cm^2 (15% to 35% of LA area) and severe mitral regurgitation corresponds to greater than 6 cm^2 (greater than 35% of LA area) (73). There is evidence that the mitral regurgitation jet area as a ratio of LA area is a poor method of quantifying the severity of mitral regurgitation. The absolute mitral regurgitation jet area is better and the narrowest diameter of the mitral regurgitation jet origin at the valve (vena contracta) is probably the best.

TABLE 66
Categorization of mitral regurgitation severity

Degree	Regurgitant fraction
Trace (0)	less than 10%
Mild (1+)	10% to 29%
Moderate (2+ to 3+)	30% to 50%
Severe (4+)	greater than 50%

PISA: Determination of the velocity of blood flow at a known distance proximal to the regurgitant orifice allows calculation of a maximum regurgitant volume (43,74-76); adding the peak velocity of blood flow, determined through continuous wave Doppler interrogation of the jet, allows calculation of an effective regurgitant orifice (ERO) (77). Using TTE or TEE, trace mitral regurgitation corresponds to a peak regurgitant volume less than 10 mL and an effective regurgitant area less than 0.1 cm^2, mild mitral regurgitation corresponds to a peak regurgitant volume of approximately 10 to 30 mL and an effective regurgitant area of 0.1 to 0.2 cm^2, moderate mitral regurgitation corresponds to a peak regurgitant volume of approximately 30 to 60 mL and a regurgitant area of 0.3 to 0.4 cm^2, and severe mitral regurgitation corresponds to a peak regurgitant volume >60 mL and a regurgitant area >0.4 cm^2 (5,56,78,79).

Quantitative Doppler flow: Determination of the total LV stroke volume and LV forward stroke volume, in the absence of significant aortic regurgitation or shunt, allows direct calculation of regurgitation volume and fraction. Using TTE or TEE, trace mitral regurgitation corresponds to a regurgitant fraction less than 10%, mild mitral regurgitation corresponds to a regurgitant fraction of 10% to 29%, moderate mitral regurgitation corresponds a regurgitant fraction of 30% to 50% and severe mitral regurgitation corresponds to a regurgitant fraction greater than 50% (80).

Vena contracta: The width or area of the regurgitant jet as it exits the regurgitant orifice should reflect both the ERO and flow rate, and therefore has the potential to accurately reflect mitral regurgitant severity (81). Using TTE or TEE (82), trace mitral regurgitation corresponds to a vena contracta width less than 0.1 cm, mild mitral regurgitation corresponds to a vena contracta width 0.1 to 0.3 cm, moderate mitral regurgitation corresponds to a vena contracta width 0.4 to 0.7 cm and severe mitral regurgitation corresponds to a vena contracta width greater than 0.7 cm (83,84).

The mitral regurgitation index is a composite of six echocardiographic variables: colour Doppler regurgitant jet area and PISA radius, continuous wave Doppler characteristics of the regurgitant jet and tricuspid regurgitant jet-derived PAP, pulse wave Doppler pulmonary venous flow pattern and two-dimensional echocardiographic estimation of LA size (85,86). Each variable is scored on a four-point scale from zero to three, the individual scores are added and the average calculated. Using TTE, trace mitral regurgitation corresponds to a mitral regurgitation index less than 1.0, mild mitral regurgitation corresponds to a mitral regurgitation index of 1.0 to 1.4, moderate mitral regurgitation corresponds to a mitral regurgitation index of 1.5 to 2.0, and severe mitral regurgitation corresponds to a mitral regurgitation index greater than 2.0 (87).

All isolated echocardiographic parameters of mitral regurgitation severity have some documented limitations (88), and none alone provide definitive evidence in themselves of the absolute degree of mitral regurgitation. Most concerning is the fact that most assess flow velocity (not volume), or a surrogate of flow velocity, at a single point in a two-dimensional plane, while mitral regurgitation is a complex, three-dimensional flow occurring during some or all of ventricular systole. Colour flow imaging (89-92) and vena contracta (93) are influenced by loading conditions and jet direction. The PISA technique is influenced by the shell chosen and distance from the orifice, as well as eccentric jets (94,95).

The qualitative and quantitative parameters of grading of mitral regurgitation generally grade as mild, moderate and severe, with moderate subdivided as mild-to-moderate and moderate-to-severe. The clinical grading of mitral regurgitation in the cardiological and surgical literature was mild, moderate and severe, as well as grades I to IV. The marginalization of moderate into mild-to-moderate and moderate-to-severe provides the opportunity for a four grade scale although the literature does not provide the absolute accuracy for comparative assessments. This four grade scale of mitral regurgitation does provide to the consensus consideration of the evidence basis for surgical management. The grading has also been confused by angiographic and echocardiographic grading but echocardiographic evaluation provides superior assessment.

Echocardiographic standards to support mitral valve reconstruction

The echocardiographer should endeavour to provide a complete analysis of the entire mitral valve apparatus and pathology, both on preoperative and intraoperative TEE (90,96-98), in support of mitral reconstruction for moderate to severe mitral regurgitation. Degenerative (fibroelastic/myxomatous) mitral valve disease is the leading cause of pathology amenable to successful mitral valve reconstruction. Ischemic mitral regurgitation remains a difficult management problem, but in the majority of instances may be amenable to mitral valve reconstruction. The results of mitral valve reconstruction remain the poorest for rheumatic mitral valve regurgitation (99).

The risk factors predictive of failed mitral valve repair for degenerative disease include anterior leaflet prolapse, use of chordal shortening, annuloplasty alone, posterior leaflet resection without annuloplasty, NYHA class III to IV heart failure, greater than 1+ (mild) mitral regurgitation postrepair and concomitant cardiac procedures (100,101).

Echocardiographic reporting should meet optimal standards for the support of successful mitral valve reconstruction both for organic (102,103) and functional (ischemic) regurgitation (104). The severity and mechanism of mitral regurgitation can be precisely determined. The mechanism of mitral regurgitation can best be delineated by differentiating the plane of the annulus and leaflet positioning in systole, ie, type I is normal leaflet motion (LM), type II is prolapsed leaflet and type III is restricted LM (99). The mitral regurgitation in type I is ascribed to either annular dilation or leaflet perforation from endocarditis and type II to overriding or prolapse of one leaflet over the other, leading to asymmetric jet(s) caused by ruptured chordae, elongated chordae or ruptured papillary muscle. Type IIIa as it relates to rheumatic mitral valve disease is due to commissural fusion and leaflet thickening or associated fused chordae. The type III restricted LM can be described in diastole (IIIa) or systole (IIIb) depending on etiology of disease. The restricted LM in functional ischemic disease (IIIb) is due to leaflet tethering and papillary muscle displacement from chronic and dysfunctional inferior LV wall due to myocardial infarction or ischemia.

The reporting requires documentation of segments of the anterior and posterior leaflets that prolapse and the presence of elongated or ruptured chordae. To obtain this quality of assessment, the interrogation of the entire coaptation line must be achieved. The entire echocardiograph imaging plane and coaptation line from medial to lateral commissure must be scanned and swept to visualise all parts of the jet for accurate estimation of severity and the location of eccentric jets (102,103).

The echocardiography report, in summary, should include any associated calcification of the annulus, the extent, site and severity of leaflet segment prolapse or fixity, the relative size of the anterior and posterior leaflets and their flexibility or fixity, the extent of systolic apposition of the leaflets, the direction of the regurgitation jet(s), and wall motion abnormalities with particular reference to the papillary muscles.

The direction of the regurgitant jet(s) is critically important in determining the mechanism of regurgitation and the type of repair required to correct the abnormality. In borderline cases of mitral regurgitation, the echocardiogram can be performed intraoperatively with preload volume loading or afterload augmentation with phenylephrine, although there are very few data to support this approach (104)

The intraoperative echocardiogram postreconstruction is also essential to determine the degree of residual mitral regurgitation and the diastolic mitral valve gradient, and to ascertain any degree of LVOT obstruction from systolic anterior motion of the anterior leaflet of the mitral valve and residual mitral regurgitation (103,105,106). The residual mitral regurgitation must be searched for by evaluated transverse and longitudinal imaging planes to assess the entire coaptation line for postrepair eccentric jets. If the residual mitral regurgitation is at least moderate and the mechanism is determined by echocardiography, the patient can be returned to CPB for a further attempt at repair. A satisfactory result is trace or at most mild (1+) mitral regurgitation (106). Residual mitral regurgitation of the moderate to severe (≥2) range is definitely an indication to redo the repair or perform MVR.

Tricuspid regurgitation

The two-dimensional echocardiographic examination usually delineates the cause of regurgitation. The causes of tricuspid regurgitation are annular dilation, prolapsing or flail leaflet, Ebstein's anomaly, Carcinoid syndrome, RV dilation or pulmonary hypertension. The semiquantitative colour Doppler examination is the most practical for assessing severity of tricuspid regurgitation, especially with central jets (107,108). Using TTE, trace tricuspid regurgitation corresponds to a maximum jet area from any accoustic window of less than 4 cm^2 (less than 20 % of RA area), mild tricuspid regurgitation is 4 to 6 cm^2, (20% to 33% of RA area), moderate tricuspid regurgitation is 6 to 10 cm^2 (33% to 66% of RA area), and severe tricuspid regurgitation is greater than 10 cm^2 (greater than 66%

of RA area). As well, severe tricuspid regurgitation should result in systolic flow reversal in the hepatic veins. Systolic flow reversal may occur in the hepatic veins with atrial fibrillation and paced rhythm in the absence of severe tricuspid regurgitation, and thus should be used with caution in the presence of these rhythm disturbances. Eccentric jets are more difficult to quantify. There is evidence that peak flow rate, regurgitant orifice area and jet momentum measurements are better correlated with eccentric jet severity than jet area (109-113). The tricuspid regurgitation vena contracta, a measure of the narrowest diameter of the tricuspid regurgitation colour flow jet as it exits the tricuspid valve into the RA, provides an additional useful estimate of tricuspid regurgitation severity. A vena contracta of greater than 6 mm indicates severe tricuspid regurgitation. However, further evaluation of these techniques is required before recommendation of their widespread use.

The continuous wave Doppler velocity of the tricuspid regurgitation jet, with an estimate of RA pressure from a two-dimensional examination of the inferior vena cava or an assumed RA pressure value, can be used to estimate pulmonary artery systolic pressure (114). A good correlation with invasive measurements has been reported (115-117). However, while the intensity of the Doppler signal will correlate with tricuspid regurgitation severity, pulmonary artery systolic pressure in itself does not reflect the severity of tricuspid regurgitation.

Pulmonary regurgitation

Colour flow Doppler echocardiography is used to determine the presence and severity of pulmonary regurgitation. Severe pulmonary regurgitation, in the absence of pulmonary hypertension, results in RV volume overload and dilation. RV systolic function is usually preserved. Pulmonary regurgitation severity can be determined from the colour flow diameter of the pulmonary regurgitation jet as well as from the degree of diastolic Doppler flow reversal in the main pulmonary artery. In addition, the pulmonary regurgitant volume and fraction can be estimated through measurement of the pulmonary and systemic stroke volumes. The pulmonary stroke volume is derived from the RV outflow tract diameter and pulsed wave Doppler flow velocity. The systemic stroke volume is usually measured in the LVOT but can also be obtained, in the absence of significant mitral regurgitation, at the mitral valve annulus. Quantitative measurements using other criteria are not usually necessary in the determination of the severity of the pulmonary regurgitation.

Respective roles of the echocardiologist and anesthesiologist in the operating room

Intraoperative TEE (IOE) has become an integral part of many cardiovascular surgical procedures and selected noncardiovascular surgeries (118-124).

Before CPB, an IOE can confirm the diagnosis, which is especially important in the setting of an incomplete or inconclusive preoperative work-up. The operating room, though, is not the place to be doing a work-up for what surgery needs to be done. The intraoperative loading conditions can cause underestimation of jet severity, particularly in mitral regurgitation. The surgical impact of this 'safety net' role of IOE has been reported to be 14% but likely varies substantially from centre to centre according to local expertise in preoperative diagnosis. After CPB, IOE is often repeated to verify the surgical result and LV function. However, the surgical or management impact of this effort has been reported to be as low as 4%.

IOE is now an integral part of the perioperative management of patients undergoing mitral and aortic valve repair (106,125). Intraoperative TEE before CPB is useful in refining the diagnosis and confirming the operative proposal. The value of IOE in mitral valve reconstructive surgery has been detailed in the reporting requirements for surgical management of severe mitral regurgitation. The IOE and preoperative TEE are important in selecting the best candidates for repair of aortic regurgitation, specifically those with congenital bicuspid aortic valve with prolapse, tricuspid leaflet aortic valve with prolapse of one cusp, pure annular or aortic root dilation or perforation of leaflets related to endocarditis. Aortic dissection with aortic regurgitation is usually feasible for repair with resuspension of the aortic valve prolapse. The assessment of aortic valve morphology, LM, aortic root structure (6,7) and direction of the regurgitant jet are essential components of preoperative TEE and pre-CPB IOE.

As IOE expands, it has become increasingly important to have well trained and dedicated physicians performing and interpreting studies. A thorough understanding of cardiac pathophysiology as well as of the strengths and limitations of IOE are crucial.

Cardiologists performing and interpreting IOE should have completed at least level two training in echocardiography in a level three echocardiography training centre performing cardiac surgery. Anesthesiologists who perform and interpret IOE should be specialised in cardiac anesthesia and should have completed a minimum of six months full time training in IOE.

Anesthesiologists performing IOE should be able to call on experienced cardiologists for consultation on difficult cases, particularly if new findings are uncovered that may require a major change in surgical approach. Ideally, this consultation should occur via a live remote link to an echocardiology reading station in order to minimise any delays in the operating room. If the preoperative work-up is thorough and reliable, IOE findings should only rarely modify surgical approach in a substantial way. If a preoperative TTE is deemed to provide incomplete information before cardiac surgery, cardiologists should proceed to elective TEE to complete the investigation and provide the cardiac surgeon with as much information as possible.

Cardiac surgeons should have echocardiograms that are of questionable quality from referring institutions routinely repeated by cardiologists in the tertiary care centre before finalizing surgical plans and obtaining consent. In complex or borderline cases, surgeons should be encouraged to review and discuss echocardiographic findings with cardiologists preoperatively.

Role of intraoperative echocardiography in mitral reconstruction

The Carpentier techniques have become the gold standards for mitral valve reconstruction (repair) for mitral regurgitation (126-129). The success of these techniques have facilitated surgical repair of severe mitral regurgitation in asymptomatic patients. To achieve this success with an experienced surgical team, immediate control by IOE is mandatory.

The use of IOE is necessary to provide guidance for systematic mitral valve repair, based on the anatomical basis of mitral regurgitation. The IOE requires a team approach based on a common language between echocardiologists and surgeons in the pre- and post-CPB periods.

The pre-CPB echocardiogram is based on valve analysis which permits classification of the mitral valve dysfunction, to assess the feasibility of repair and to predict the techniques to be used. Valve analysis is based on four stages:

- Functional analysis;
- Segmental analysis;
- Etiology and analysis of lesions;
- Analysis of the risk of SAM.

A: Functional analysis: The functional analysis corresponds to Carpentier classification (126) according to LM (LM):

Type I (normal LM) due to annular dilation or perforation;

Type II (excessive LM) due to prolapse caused by elongation or rupture of papillary muscle or chordae;

Type III (restrictive LM) in diastole (IIIa) or in systole (IIIb).

The functional analysis for reconstructive surgery is dependent on the pathological status of the valve and is also documented in the Duran classification (129):

Type I Mobility is normal;

Type II Mobility is augmented;

Type III Mobility is restricted.

This functional classification is useful from a practical surgical point of view but is far more useful to analyze each component of the mitral apparatus to determine whether it is normal, augmented or elongated, or reduced or shortened. Any patient can have a combination of lesions, such as dilated annulus with restricted LM and elongated chordae or, for instance, normal annulus with shortened chordae.

The types of lesions encountered according to the mitral valve pathology are demonstrated in Table 67.

B: Segmental analysis: The segmental analysis evaluates the eight segments of the mitral valve:

- Commissures (2), anterior and posterior;
- Scallops (6) of both leaflets (anterior and posterior)
  - Lateral scallops (A1 and P1)
  - Middle scallops (A2 and P2)
  - Medial scallops (A3 and P3).

The echocardiographer will report to the surgeon, for example, which scallop is involved in the dysfunction, eg, mitral regurgitation type II P2 to P3.

C: Etiology and analysis of lesions: The etiology and lesional analysis defines two key criteria to determine the feasibility of repair, namely the amount as well as the quality of tissue available for repair.

D: Analysis of the risk of SAM: The risk of SAM is defined by three factors: excessive tissue (Barlow disease), narrow mitral-aortic angle and nondilated left ventricle.

The echocardiograher also advises the surgeon of the size of the left atrium for the surgical approach and the presence of aortic regurgitation for the mode of delivery of cardioplegia.

The post-CPB IOE is performed after weaning from CPB, cannulae in place, and under similar hemodynamic conditions as pre-CPB in terms of LV function and loading conditions.

The post-CPB IOE will successively assess the following:

1. The leaflet coaptation in two-dimensional echocardiogram;
2. The presence of residual mitral regurgitation with analysis of its mechanism and importance (almost 20% of transient residual mitral regurgitation is mainly due to LV dysfunction. If residual mitral regurgitation is equal to or more than 2+, the patient is usually returned to CPB for further surgery);
3. The existence of SAM which is due to a discrepancy between excess of leaflet tissue (posterior or anterior) and a small surface area (ring too small). This may require a sliding plasty of the posterior leaflet or a larger ring;
4. All other anatomic structures, particularly aortic valve, tricuspid valve and ascending aorta. These should be explored to detect iatrogenic complications.

The impact and incremental value of IOE have been demonstrated to decrease the incidence of reoperation but not mortality (except for ischemic mitral regurgitation).

IOE is critical and should be systematic in mitral valve repair. Pre-CPB examination provides a ‘road map’ for the surgeon in a team approach, providing a guide to repair. The post-CPB examination assures the quality of the repair and provides a true safety net for the surgeon.

Management following valvular replacement or reconstruction: Short and long- term

The follow-up of patients following valvular replacement or reconstruction should include clinical assessment, laboratory assessment (if indicated) and echocardiography.

Doppler echocardiography should be performed early after operation. Longitudinal follow-up is the best way to detect

TABLE 67
Types of lesions encountered according to mitral valve pathology

Location	Rheumatic	Barlow s	Degenerative	Ischemic
Annulus	Normal/dilated	Dilated	Dilated	Normal/dilated
Leaflets	Thick, retracted	Thick, excess tissue	Thin	Thin
Commissures	Fused	Normal	Normal	Normal
Chords	Thick, short	Thick, long	Thin, long	Normal/ruptured
Papillary Muscle	Thick	Normal	Normal	Normal/fibrosed/ruptured

TABLE 68
Recommendations for surveillance of valve reconstruction, valve replacement, as well as autograft aortic root reconstruction and pulmonary root replacement

Type of valve	Interval
Autografts	Operating room, discharge/30 days, 6 to 12 months, and yearly or any clinical suspicion of dysfunction
Valve reconstruction	Discharge/30 days, 6 to 12 months, 5 and 10 years or any clinical suspicion of dysfunction
Mechanical prostheses	Discharge/30 days, 6 to 12 months or any clinical suspicion of dysfunction
Heterograft bioprostheses	Discharge/30 days, 6 to 12 months, 5 years and annually after 7 years for mitral valve replacement and after 10 years for aortic valve replacement or any clinical suspicion of dysfunction
Allograft bioprostheses (aortic, mitral, pulmonary or tricuspid)	Discharge/30 days, 6 to 12 months, 5 years and annually after 5 years or any clinical suspicion of dysfunction

TABLE 69
Use of echocardiography in assessment of valvular disease (transesophageal echocardiography and transthoracic echocardiography)

Valve anatomy, etiology of disease and evaluation of stenosis severity
Aortic stenosis
Jet velocity (maximal transvalvular)
Gradients (maximum and mean)
Area (by the continuity equation)
Mitral stenosis
Gradient (mean)
Valve area (by two-dimensional planimetry, pressure half-time and/or the continuity equation)
Prosthetic valves
Jet velocity (maximal transprosthetic)
Gradients (peak and mean)
Valve area (by the continuity equation only)
Evaluation of regurgitant severity
Colour Doppler flow imaging (0 to 4+ scale)
Continuous wave Doppler signal strength or amplitude
Flow reversals (pulmonary veins for mitral regurgitation, descending aorta for aortic regurgitation, and hepatic veins for tricuspid regurgitation)
Vena contracta (diameter of colour flow jet at regurgitant orifice)
Quantitation of regurgitant volume, regurgitant fraction and orifice area in selected cases
Prosthetic valve regurgitation*
Left ventricular and atrium
Left atrial enlargement
Left atrial thrombus*
Left ventricular end-diastolic and end-systolic dimensions and volumes
Left ventricular ejection fraction
Left ventricular dP/dt (from mitral regurgitation jet)
Left ventricular myocardial performance index
Right heart
Right atrial enlargement
Right atrial thrombus
Pulmonary artery systolic pressure (from the tricuspid regurgitation jet velocity plus estimated central venous pressure (CVP)
Right ventricular size and systolic function
Right ventricular myocardial performance index
Tricuspid regurgitation
Pulmonary artery systolic pressure (from the tricuspid regurgitation jet velocity plus estimated CVP)
Endocarditis
Detection of valvular vegetations*
Evaluation of the extent of valve dysfunction
Evaluation of complications (abscess, fistula)*

**Transesophageal imaging is usually necessary for accurate diagnosis. dP/dt Rate of rise in pressure over time.*

valve degeneration or dysfunction after operation and an early study is necessary to serve as a baseline for future comparisons. Ideally, this study should be performed between five and 30 days after operation, given that an earlier study may not be representative because patients are often in a hyperdynamic state during the first few days after operation. If a high gradient is detected during this early study, one should not necessarily conclude that there is a dysfunction and should consider the possibility of a hyperdynamic state or of patient-prosthesis mismatch (130,131), which is identified by calculating both the projected and the actual indexed effective orifice areas (132-134). In the case of a stentless valve, one should also consider that gradients and effective orifice area may improve somewhat during the first few months after operation (135,136).

The next echocardiogram should be performed between six to 12 months after surgery, after which there is no firm recommendation except that a study should be performed at the slightest suspicion of dysfunction. Dysfunction may be suspected by a reduction of one functional class from the maximal recovery NYHA functional class. The recommended follow-up interval for echocardiography can be based on the type of prosthesis and the documented knowledge of potential dysfunction. The follow-up interval can be up to five years except for biological prostheses that have exceeded their projected lifespans (137,138) or if the five-year study has started to show signs of deterioration, in which case follow-up studies should be performed yearly (138) (Tables 68 and 69).

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SECTION XII: ADVANCES IN PROSTHETIC VALVE DESIGN AND FUNCTION

Technology continues to strive to bring forward advances that will improve the durability of bioprostheses and reduce the thrombogenicity of mechanical prostheses. The current status of technological progress shows promise in reaching these objectives.

MECHANICAL PROSTHESES

Mechanical prosthetic devices have been available for approximately four decades. From the early generation of heart valves, only the Starr-Edwards ball valve design remains in clinical use today. The ball valve design was the gold standard until the late 1970s. The developments of the last two decades are an attempt to address a number of problems associated with the first generation of mechanical devices. Currently available mechanical valves have been designed with a lower profile and a more effective orifice area, to improve hemodynamics. These valves are made with thromboresistant materials to reduce the incidence of thromboembolic complications.

The current generation of mechanical heart valves are either monoleaflet or bileaflet prostheses. They are constructed with pyrolitic carbon leaftlets with either titanium or pyrolitic carbon housing. Tungsten or graphite is used as the supporting scaffolding over which the pyrolitic carbon is laid. The principle mechanical prostheses available worldwide are shown in Table 70.

Mechanical prostheses failure modes

Structural failure of mechanical prostheses has been observed with both monoleaflet (disc) and bileaflet designs. The Björk-Shiley tilting disc design has been withdrawn from the market while the Duromedics bileaflet prosthesis was reintroduced as the Edwards-Tekna (Edwards Lifesciences, USA) valve following design modifications. The failure mode of the Björk-Shiley prosthesis is failure of the welded outlet strut with resultant embolization of the disc. To gain insight into the failure mechanism, a metallurgical analysis was carried out on the fractured struts of this device. This demonstrated that welding imperfections and metal fatigue were the major determinants of strut fracture.

With bileaflet mechanical valves, the most critical design element is the hinge mechanism. The hinges are the area of highest stress. Factors that influence wear are the geometry of the coupling elements undergoing impact wear (flat to flat versus curved to flat), the mechanism of kinetic coupling between the moving parts that are subjected to wear (sliding versus rolling versus rotation), and finally the materials that contact each other (pyrolytic carbon to pyrolytic carbon, pyrolytic carbon to metal, pyrolytic carbon to composite carbon metal).

In the case of the Duromedics valve, a cavitation injury of the disc and housing or pivot ball was found to occur with resultant fracture of the pivot ball and embolization of the disc (1). The causes of the fractures were considered related to clustered microporosity, cavitation erosion and asymmetrical leaflet closure with uneven distribution of the stress load. The design modifications undertaken by Edwards Lifesciences (Baxter Healthcare Corp) were aimed at changing the spatial relationship of the seating lip radius of the leaflet to the contact area. A silicone compliant ring was inserted into the housing to act as a cushion and reduce the leaflet closing impact. Asymmetrical leaflet closure was also minimized by a modification of the dimensional specifications of the flat to flat clearance, making this relationship much tighter. The flat to flat clearance is the clearance between the flat side portion of the leaflet and the flat portion of the valve housing.

The Mechanical Device Registry has provided the opportunity to analyze failure mechanisms for pyrolytic carbon valves in detail. The findings indicate that approximately 50% of all failures occur between the time the valves are removed from packaging to the time surgery is completed. The most common cause of failure during implantation is leaflet fracture. This occurs either from excessive pressure applied in flexure or from over opening. The authors found one case of late failure (20 months postimplantation) in a St Jude Medical bileaflet valve. When this device was inspected, multiple fractures were noted near the pivot guards of the orifice ring and adjacent to the pivots on one side. Following load testing of this device and control valves, it was concluded that excessive load had been applied to the open leaflets during implantation. These results indicate the importance of careful surgical technique during valve implantation with avoidance of undue pressure, particularly while seating the prosthesis.

The most common reasons for mechanical valve failure are pannus formation and thrombosis. Pannus creep most often occurs on the undersurface of the valve and leads to progressive stenosis. It may also impede leaflet clearance. Thrombosis is often a catastrophic event.

Recent advances in mechanical prostheses

The most significant changes in mechanical heart valves of the last decade have focused on two components, namely, the sewing ring and the ability to rotate the valve after implantation. North American surgeons will be most familiar with the alterations of the sewing ring of the St Jude Medical and CarboMedics (Carbomedics, USA) prostheses. The St Jude Medical standard aortic valve has part of the sewing cuff intra-annular, whereas in the hemodynamic performance (HP) series, the cuff fabric is shifted to an entirely supra-annular position. The St Jude Medical Regent prosthesis shifts the carbon rim from intra-annular to entirely supra-annular. While these modifications have resulted in better hemodynamics, there is a greater potential for paravalvular leaks, particularly in patients where the aortic annulus is heavily calcified. The CarboMedics Top Hat valve has a modified sewing ring that allows for the placement of the device in a supra-annular position. This modification allows for the implantation of a valve on average one size larger for any given annulus. This results in improved hemodynamics.

There has been development of sewing cuff impregnation with antibiotics or bactericidal metal to prevent or reduce the risk of PVE. The safety and efficacy of the St Jude Medical Silzone (silver nitrate incorporated in the sewing cuff) was under evaluation in the Artificial Valve Endocarditis Reduction Trial (AVERT) multicentre clinical trial (2-5), but the study was discontinued due to increased incidence of paravalvular leak in the silzone cohort. It is conceivable that the silver metal influenced healing at the sewing cuff of the prosthesis. The newer generation mechanical prostheses, eg, the Edwards-MIRA (Edwards Lifesciences, USA) (Sorin Bicarbon mechanical prosthesis with a modified sewing ring), ATS

TABLE 70
Principle mechanical prostheses that are available worldwide

Design	Manufacturer	Leaflet material	Housing material	Opening angle
Monoleaflet	Bj rk-Shiley	Pyrolytic carbon	Cobalt-chromium	70
	Sorin Monoleaflet	Pyrolytic carbon	Cobalt-chromium Carbofil	70
	Medtronic-Hall	Pyrolytic carbon	Titanium-pyrolitic carbon	70 to 75
	Omnicarbon	Pyrolytic carbon	Pyrolytic carbon	80
	Ultracor	Tungsten-pyrolitic carbon	Titanium	68 to 73
Bileaflet	St Jude Medical	Pyrolytic carbon	Pyrolytic carbon	85
	CarboMedics	Pyrolytic carbon	Pyrolytic carbon	78
	Edwards-Tekna	Tungsten-pyrolitic carbon	Pyrolytic carbon	73 to 77
	Sorin Bicarbon, Edwards MIRA, Sorin Allcarbon	Pyrolytic carbon	Titanium Carbofil	80
	ATS	Pyrolytic carbon	Pyrolytic carbon	85
	On-X	Tungsten-pyrolitic carbon	Pyrolytic carbon	85

(Advancing The Standard) (ATS Inc, USA) and On-X (Medical Carbon Research Institute, USA) have just completed regulatory clinical trials. Of interest to the 'valve aficionado', the engineering design group that produced the St Jude Medical and CarboMedics valves also designed the ATS prosthesis.

Mechanical technologies for the future

The failure mode of the Medtronic Parallel (Medtronic Inc, USA) mechanical prosthesis was an unacceptable thrombosis complication rate and the investigational trial was terminated voluntarily by the manufacturer (6). The extensive study of this prosthesis failure by the manufacturer identified studies for flow fields within the hinge region of a bileaflet prosthesis and serves as a standard for assessment of future prosthesis designs. The microstructural flow analysis within the hinge pocket was made possible by the creation of an optically clear, dimensionally accurate reproduction of the prosthesis. This formulation of the bileaflet prosthesis was made possible by a clear epoxy resin housing. This replica of the prosthesis facilitated flow visualization, computational fluid dynamics modelling, laser Doppler velocimetry measurements and laser Doppler anemometry measurements. The thrombus formation on the hinge mechanism of the Medtronic Parallel prosthesis correlated with multiple zones of stagnation, distributed flow and elevated shear stresses during the leakage flow phase.

These investigative technologies should be used in the development of all future prosthetic designs. There is the likelihood of reduced thromboembolism and thrombosis with future prostheses and the potential for reduction of anticoagulation levels.

CURRENT TISSUE VALVE TECHNOLOGY

Glutaraldehyde has been used for over a quarter century to preserve biological tissue, both porcine aortic and bovine pericardium, for formulation of bioprostheses. Glutaraldehyde fixed tissue has increased tensile properties. However, the fixation process also alters the mechanical and viscoelastic characteristics of the leaflets, producing abnormal valve function, leading to overstressing and eventually to valve degeneration and failure. This concept can be understood by an analysis of the internal mechanical stress that bioprosthetic valves are subjected to: (i) tensile stress which results primarily from hydrostatic forces applied while the valve is closed, (ii) internal shear stress as various parts of the valve flex and bend throughout the cardiac cycle.

Normal valve leaflets are made from a very pliable, spongy material that contains fibres resistant to stretch but not to compression. It is this low resistance to axial compressive forces that is likely responsible for the extreme pliability of the normal tissue. During valve opening, tissue shear properties minimize tissue buckling, stress concentration and collagen fibre damage by allowing the layers that comprise the valve tissue to slide across one another much like the pages in a book during bending. However, following gluteraldehyde fixation, the tissues become up to four times stiffer than fresh tissue (7). The fibres are immobilized within the remnants of the mucopolysaccharide matrix by the fixation process, which induces molecular crosslinks, and the tissue therefore becomes more resistant to the axial compressive forces that accompany bending. As a result, the stiffer tissue buckles during bending. Once buckling begins, it returns to the same spot with each successive heart beat and the collagen fibres may fatigue until they break. Tissue buckling is particularly prominent when the valve is mounted onto a stent. This is because the leaflets of stent-mounted valves do not open fully. Stent mounting not only produces higher transvalvular gradients but also causes premature valve failure. Stenting of biological valves is therefore clearly disadvantageous. In the brief period in which homografts were stented, the average life expectancy of the valve was less than 10 years. In sharp contrast, nonstented homografts have a 10-year freedom from valve degeneration of 88% to 90%.

Tissue buckling promotes calcification that predictably begins and increases in areas of leaflet flexion where deformations are maximal (7-14). Typically, this occurs at the commissures and the base of the leaflets. Elimination of the supporting stents and sewing ring is thought to preserve normal aortic valve and root interactions. This in turn minimizes tissue buckling and should increase valve longevity. In an experimental study with growing pigs who underwent AVR, both the speed and extent of valve degeneration was less with a stentless bioprosthesis than with a stented bioprosthesis. These results support the hypothesis that valve leaflets are subjected to less bending when normal valve and root interactions are maintained.

Stentless porcine xenografts were reintroduced into clinical practice a decade ago in the hope that elimination of the sewing ring and supporting stent would produce a device with superior hemodynamics and enhanced longevity (15-17). These devices took into account many of the principles just discussed. There is a large and compelling body of evidence that these devices are hemodynamically superior to conventional stented valves. Furthermore, to date, in two large international trials, no Medtronic Freestyle (Medtronic Inc) and Toronto SPV (St Jude Medical Inc) stentless valves have been explanted due to primary structural failure (Medtronic Inc, St Jude Medical Inc, personal communication). However, few patients have yet to reach the 10- to 12-year follow-up interval. Many more years of follow-up will be required to determine whether these valves will function longer than conventional stented bioprostheses.

There have been other strategies introduced over the past 10 to 15 years to reduce long term tissue degeneration. These have related primarily to normalization of tissue collagen configuration at the time of glutaraldehyde fixation, as well as to control of tissue calcification with the use of surfactant treatment (18).

The pressure the tissue is subjected to during the fixation process significantly alters the normal architecture of the aortic valve leaflet. Examination of the cuspal tissue of commercially processed xenografts demonstrate near complete loss of transverse cuspal ridges and collagen crimp in valves fixed at either 80 mmHg or 1.5/80 mmHg while valves fixed at 1.5 mmHg show intermediate features. In contrast, valves fixed at zero pressure retain a collagen architecture virtually identical to that of native unfixed porcine aortic valve cusps (7). It is thought that the role of the collagen crimp is to prevent tissue buckling that, in turn, will retard mineralization of the cuspal tissues (7). The 10-year experience with the Medtronic Intact (Medtronic Inc) (zero pressure fixed) valve has been reported (19). In the aortic position, there were no cases of primary structural degeneration in patients over 60 years of age and only one case of valve failure in individuals over 40 years of age.

Considerable effort has been made by both industry and investigators to develop compounds that will retard or possibly completely eliminate leaflet calcification. It is believed that the exposed amine residues of the glutaraldehyde molecule promote tissue calcification (8,9). Surfactants, particularly sodium dodecyl sulfate (T6) (Hancock II, Medtronic Inc, USA), polysorbate 80 (Carpentier-Edwards Standard and Supra-Annular, Edwards Lifesciences, USA) and toluidine blue (Medtronic Intact, Medtronic Inc) have been incorporated in the preservation process (20). While these compounds do not alter the collagen architecture, their efficacy as anticalcificants is limited.

The control of residual aldehydes, following glutaraldehyde fixation, with epsilon amino oleic acid (EOA) has been extensively evaluated and used in the Medtronic Mosaic (Medtronic Inc) stented and Freestyle stentless porcine bioprostheses (21-23).

Of the antimineralization compounds currently in clinical use, EOA shows the most promise. While EOA has been shown to effectively mitigate calcification of the aortic leaflet, it does not prevent calcification of the aortic wall. Finally, the No-React detoxification process has been proposed as a method of preventing calcification of glutaraldehyde fixed tissue (24). Detoxification with homocysteic acid is used in Sorin products (Sorin Group Inc).

Strategies for improving or substituting glutaraldehyde fixation

Pretreatment of the tissue with ethanol before glutaraldehyde fixation may play a role in future anticalcification strategies (25). Ethanol pretreatment significantly reduces the water content of the leaflets, reduces cholesterol uptake and increases the resistance to collagenase digestion. However, cuspal glutaraldehyde content is not changed by ethanol pretreatment. The combination of ethanol pretreatment with an anticalcification agent and zero pressure fixation may produce optimal results with the technology currently being employed in clinical practice. Ethanol pretreatment when combined with aluminum chloride has been shown in investigative endeavours to inhibit calcification in both the cusps and aortic wall. These approaches are being evaluated clinically.

There are several alternatives to glutaraldehyde fixation in the experimental phases of investigation. The agents being studied are either incorporated into the tissue (eg, epoxide or glutaraldehyde) or act as promoters of the crosslinking process (eg, acyl azide or dye mediated photo-oxidation) (26-36). The epoxide compounds, such as denacol, form strong crosslinks with the carboxyl and amino protein groups (37,38).

The compounds acyl azide and carbodiimide facilitate crosslinking without incorporating the agents into the fixed tissue (26,39). The compounds provide the same stability to tissue fixation as glutaraldehyde when assessed for thermal stability and resistance to collagenase digestion. The Ultifix method (carbodiimide) uses a coupler to link the amine and carboxyl moities by the formation of a Schiff base (26). If the treated tissue is not exposed at any time to glutaraldehyde, only the valve cusps and not the wall will show significant reduction to calcification (29-31,33-35).

Dye mediated photo-oxidation is also a promoting process of collagen crosslinking. The tissue, either pericardium or porcine, is treated with an aqueous solution including the photo-oxidative dye and light irradiated. The stability of photo-oxidized tissue is similar to that of glutaraldehyde. Photo-oxidation has been proposed to replace glutaraldehyde, and has been used to fix both bovine pericardial tissue and porcine aortic valve tissue.

Detoxification processes have been incorporated into the glutaraldehyde cross-linking of heterographic tissue. Detoxification with homocysteic acid post-glutaraldehyde is utilized to neutralize unbound aldehydes. Detoxification processes have been shown to support a degree of endothelium on heterographic tissue, which may provide resistance to endocarditis similar to that of allografts (40-43).

Investigative clinical trials of at least some of these agents should commence within the next few years.

In search of the holy grail

Tissue engineering strategies are starting to evolve (44-62). The premise is to create a living valve that will not be rejected by the patient's own immune system. Novel tissue engineering approaches are being investigated to improve replacement heart valve durability. These tissue engineering techniques are focused on fabricating the intricate architecture of the valve leaflets. Scaffolds have been developed from synthetic and naturally occurring polymers and then cellularized from host endothelial cells in tissue culture. Besides synthetic scaffolds, both heterograft and allograft valvular tissue can be decellularized and repopulated in vitro with the predetermined host cells (45,46,62). Preoperatively, endothelial cells would be harvested from the patient. These cells would then be cultured and incorporated into the scaffold. A living valve with recipient-specific endothelial cells would then be implanted at the time of surgery. On a theoretical basis, these approaches are the most attractive. They are, however, also the most complicated.

More recently, Elkins et al (45) have developed stentless allograft bioprosthetic valves that have been fabricated from acellular tissues, cryopreserved and implanted as pulmonary root replacements in juvenile sheep. After 150 days, the grafts showed intact leaflets with ingrowth of host fibroblastoid cells in all explanted porcine valves and no evidence of calcification. Elkins et al (45) have implanted porcine decellularized conduits in both the pulmonary and aortic outflow tracts in humans.

The decellularization process with heterografts replaces the use of glutaraldehyde for collagen crosslinking to limit xenograft antigenicity. The predominant issues with this modality of tissue engineering is the maintenance of balancing scaffold disappearance and interstitial cell reseeding, and support a desirable host cellular response not susceptible to antigenic recognition and immunological rejection.

In summary, the current status of achieving tissue engineered heart valves with autologous cells is to have scaffolds of either biodegradable polymers or biological extracellular matrices. The polymeric scaffolds are biodegradable and are used for cell anchorage, proliferation and differentiation (55-59). The thermoplastic biopolyesters that have been studied to mould a trileaflet valve scaffold are polyglycolic acid, polyhydroxyalkanoate and poly-4-hydroxybutrate (55,58). The disadvantages of these synthetic polymers are stiffness, thickness and nonpliability. The in vitro seeding to form a three-dimensional matrix is conducted with fibroblasts, smooth muscle cells and endothelial cells. The xenogenic or allogenic biological extracellular matrices may be the most promising, with decellularization and cryopreservation followed by recellularization with autologous myofibroblasts and endothelial cells either in vitro or in vivo. These modalities provide the opportunity for a physiological environment that is nonimmunogenic with the propensity for calcification.

Given the current knowledge and understanding, it is not likely that commercially prepared tissue engineered valves will be available for several years.

There is extensive research on polyetherurethane polymer alternatives for valve prostheses. Polyurethane flexible prostheses are being evaluated in sheep models (63). There is also preliminary investigation on percutaneous aortic valves, as well as pulmonary valves and implementation (64). These technologies will require years of development and evaluation.

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SECTION XIII: ANTITHROMBOTIC THERAPY FOR PROSTHETIC HEART VALVES

Patients with prosthetic heart valves are at risk of systemic thromboembolism, most commonly cerebral. The risk of systemic embolization is greater with mechanical than bioprosthetic valves, and with prosthetic mitral than aortic valves. Embolization risk is increased with associated atrial fibrillation (1-4). For patients with mechanical prosthetic valves, the risk is lifelong (5). For patients with tissue prosthetic valves who are in sinus rhythm, the risk related to the prosthesis is minimal. Mechanical prostheses have the added risk of bleeding from anticoagulants. The risk of emboli is considered to be higher in the early days and a few months following surgery.

Biological prostheses

During the first three months following implantation, endothelization of the sewing cuff occurs and anticoagulation is generally recommended, especially for MVR. It should be noted that several centres only use acetylsalicylic acid therapy specifically for AVR. Following the three-month period, only patients with associated risk factors for thromboembolism, such as atrial fibrillation, previous thromboembolism, large cardiac thrombus, ventricular dysfunction or hypercoagulable conditions, are candidates for lifelong anticoagulation. Atrial fibrillation is the major risk factor while the combination of atrial fibrillation, history of prior thromboembolism or thrombi in the left atrium has higher rates of thromboembolism. The recommended target INR range for these circumstances is 2.0 to 3.0 for both the aortic and mitral positions. Anticoagulation should also be considered, specifically in cases of severe LV dysfunction (ejection fraction less than 0.30).

Mechanical prostheses

For mechanical prostheses (bileaflet or monoleaflet) in the aortic position, the INR recommended range is 2.0 to 3.0. In the mitral position, the recommended range is 2.5 to 3.5. The recommended range for the Starr-Edwards prosthesis is 3.0 to 4.0 for both positions. Some prostheses (tilting disk) are thought to have a higher risk of thromboembolism. These prostheses may require a higher INR or the addition of acetylsalicylic acid (81 mg/day). Acetylsalicylic acid in combination is particularly recommended for patients who have an embolus on anticoagulant therapy, known vascular disease or susceptibility to hypercoagulability.

The early risk of thromboembolism after insertion of the prosthetic valve, until anticoagulant therapeutic levels are attained, may be an indication for heparin therapy. This management modality is controversial (Table 71).

TABLE 71
Recommendations for antithrombotic therapy in patients with prosthetic heart valves (6-33)

Indication mechanical prosthetic valve		Class	
Mechanical (all oral anticoagulants)		I	C
Unfractionated heparin or low molecular weight heparin until INR therapeutic, 2 days		II	C
Aortic valve replacement			
Bileaflet St Jude Medical*	Warfarin, INR 2.0 to 3.0	I	A
Bileaflet CarboMedics*	Warfarin, INR 2.0 to 3.0	I	C
Tilting disc Medtronic Hall*	Warfarin, INR 2.0 to 3.0	I	C
Bileaflet	Warfarin, INR 2.5 to 3.5	I	C
Bileaflet ( )	Warfarin, INR 2.0 to 3.0 plus ASA, 80 to 100 mg/d	II	C
Mitral valve replacement			
Bileaflet and tilting disc	Warfarin, INR 2.5 to 3.5	I	C
Bileaflet and tilting disc ( )	Warfarin, INR 2.0 to 3.0 plus ASA, 80 to 100 mg/day	II	C
Mechanical (aortic-mitral)§	Warfarin, INR 2.5 to 3.5 plus ASA, 80 to 100 mg/day	I	C
Mechanical (aortic-mitral)¶	Warfarin, INR 2.5 to 3.5 plus ASA, 80 to 100 mg/day	I	C

**Sinus rhythm and left atrium normal size; Atrial fibrillation; Alternative recommendation; §Risk factors: atrial fibrillation, left ventricular dysfunction, previous thromboembolism and hypercoagulable conditions; ¶Systemic embolism. ASA Acetylsalicylic acid; INR International normalization ratio*

Indication bioprosthetic valves		Class	
Three months after valve replacement			
Aortic	ASA/warfarin	II	C
Mitral	Warfarin	I	C
Heparin (low molecular weight or unfractionated) until INR therapeutic: 2 days		II	C
Three months after valve replacement			
Aortic or mitral	Warfarin INR 2.0 to 3.0	I	A
More than three months after valve replacement			
Aortic or mitral*	Warfarin INR 2.0 to 3.0	I	C
Aortic or mitral	Warfarin INR 2.0 to 3.0	I	C
Aortic or mitral	Warfarin INR 2.5 to 3.0 for 3 to 12 months	II	C
Aortic or mitral§	ASA 80 mg/day	II	C
Contraindication			
Mechanical, no warfarin therapy		III	C
Mechanical, ASA therapy		III	C
Bioprostheses, no warfarin or ASA therapy		III	C

**Atrial fibrillation; Left atrial thrombus at surgery; History of systemic embolism; §Sinus rhythm. ASA Acetylsalicylic acid; INR International normalization ratio*

Antithrombotic therapy: Noncardiac surgery and dental care

The risk of increased bleeding during a procedure performed on a patient receiving antithrombotic therapy must be weighed against the increased risk of thromboembolism caused by stopping the therapy (33-36). The risk is minimal when stopping for a few days except in very high risk patients (three or more risk factors). Patients at very high risk should be treated with heparin until INR therapeutic levels are achieved. The risk factors are atrial fibrillation, previous thromboembolism, a hypercoagulable condition, mechanical prosthesis and LV dysfunction.

There are several anticoagulation preferences to manage patients with mechanical valves who are undergoing elective surgery (37). Preoperative and postoperative intravenous heparin regimes are the most frequently selected anticoagulation options. The risk of thromboembolism, but not the risk of bleeding, influence the aggressiveness of anticoagulant management and if heparin is selected, the risk of bleeding influences the timing of heparin initiation (Table 72).

TABLE 72
Anticoagulation options*

Preoperative anticoagulation options
a. Admit to hospital 2 to 4 days preoperatively for full-dose IV heparin
b. Outpatient full-dose SC heparin or LMWH
c. Nothing else other than stopping warfarin preoperatively
d. Other
Postoperative anticoagulation options
a. Full-dose inhospital IV heparin until INR therapeutic
Heparin to be restarted
<6 h postoperatively
6 to 12 h postoperatively
>12 h postoperatively
b. Early discharge home with full-dose SC heparin or LMWH until INR therapeutic
c. Low-dose inhospital SC heparin or LMWH until INR therapeutic
d. Nothing else other than restarting warfarin postoperatively
e. Other

**These options are given in addition to stopping warfarin 4 to 5 days preoperatively and restarting warfarin 1 to 2 days postoperatively. Full-dose subcutaneous (SC)/intravenous (IV) heparin or SC low molecular weight heparin (LMWH) is the dose recommended for treatment of venous thromboembolism or acute coronary syndromes; low-dose SC heparin or LMWH is the dose recommended as prophylaxis for venous thromboembolism. INR International normalization ratio*

Thrombosis of prosthetic heart valves

Prosthetic valve dysfunction may be caused by thrombus, pannus ingrowth or a combination. Pannus ingrowth can only be managed surgically. The effectiveness of thrombolytic therapy for management of prosthesis thrombosis is dependent to some degree on the duration and maturation of the thrombus (38-67). Thrombolytic therapy is effective in approximately 80% of cases. The acute mortality has been reported to be 6%. The risks of thrombolytic therapy are thromboembolism 12% (stroke 3% to 10%), major bleeding 5% and recurrent thrombosis 11% (46-48). Patients with large, obstructive thrombus, and NYHA class III or IV may require early or immediate reoperation. The absolute indications for emergency reoperation are cardiogenic shock and pulmonary edema. Urokinase and streptokinase are the most frequently used thrombolytic agents. The dosing regimens are as follows:

- Streptokinase: 250,000 units bolus over 30 min and then 100,000 units/h;
- Urokinase: 4,400 units/kg bolus over 10 to 15 min and then 4,400 units/kg/h;
- Alteplase: various dosing regimens for total of 100 mg.

The response to thrombolytic therapy is evaluated by auscultation, Doppler echocardiography, TEE or fluoroscopy. The duration of therapy is 24 to 72 h depending on hemodynamic recovery; there should be response to therapy within 24 h. Intravenous heparin and return to therapeutic anticoagulation should follow successful thrombolysis. The therapeutic level should be INR 3.5 to 4.0 depending on prosthesis type and valve position.

Antithrombotic management can generally be optimized by patient-managed home anticoagulation (68-83). The German Association of Self Management of Oral Anticogulation has determined that self management is feasible and safe. Self-management has been shown to improve accuracy of anticoagulation and to reduce the risk of thromboembolism and hemorrhage. In published documentation, patients met the target INR 80% of the time while family physicians did so in only 62%; only 8% of cases were unable to continue on self-management anticoagulation. A further study reported that a target INR was met at approximately 80% of evaluations in either self-management or clinic management. The German experience has determined that 50% to 60% of all patients are suitable candidates for self-management. Weekly self-testing and self-dosing have been shown to lead to better control of anticoagulation than standard treatment by anticoagulant clinic management. Self-management is better appreciated by patients and has the significant advantage to reduce severe thromboembolic and hemorrhagic complications.

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SECTION XIV: INFECTIVE ENDOCARDITIS

Surgery has a significant role in the management of both native and PVE. The ACC and AHA Guidelines for Management of Valvular Heart Disease provided recommendations for surgery in the management of both NVE and PVE (1-4).

The surgical management of infective endocarditis, whether native or PVE, can be a definite challenge. The timing of surgical management and of course early diagnosis, as well as the surgical procedure, are important in minimizing the risk of infective endocarditis (5-14). Surgical referral is often pre-empted because of necrotizing lesions, severe hemodynamic impairment, initial multisystem failure and cerebrovascular accidents. Early surgery is usually performed for persistent sepsis, hemodynamic instability or arterial embolism; or after four to six weeks of antibiotic therapy.

The indications for operation for infective endocarditis are well defined and generally accepted; these include hemodynamic compromise, persistent sepsis despite antibiotic treatment, peripheral embolism of vegetations, aortic root abscesses, onset of conduction system disturbances, prosthetic valve endocarditis or fungal endocarditis (12,15-18). Surgery is usually performed for 'medical failures' such as uncontrolled sepsis, severely compromised hemodynamics and previous multiple septic embolisms (19). Destructive aortic valve endocarditis can cause aortic root abscess, partial aortoventricular separation, left ventriculo-atrial fistulae and aorto-RV fistulae. These serious destructive complications involve the annulus and the fibrous skeleton of the heart.

Transesophageal echocardiography (TEE) provides guidance to the best strategy in high risk patients (20-22). Besides the evaluation of destructive lesions, TEE is optimal to detect and monitor vegetations (21). The risk of embolic events increases threefold with vegetations greater than 10 mm. The highest risks of neurological complications from embolic events occur with left-sided NVE, especially when caused by *Staphylococcus aureus*. The identification of cerebral septic emboli is of paramount importance. The concern about performing a valvular operation in infective endocarditis complicated with cerebral septic emboli is the possibility of septic mycotic aneurysm or of hemorrhage into the infarcted zone during CPB (9). Cerebral septic emboli are not always symptomatic and should be systemically screened in the presence of infective endocarditis. Some recommend that systematic cerebral CT should be performed in the presence of any infective endocarditis.

The predictors of early mortality and subsequent survival are age, sex, social status, drug abuse, diabetes mellitus, embolizations, site of infective endocarditis, positivity of blood cultures, preoperative NYHA status, active or healed infective endocarditis, indication for surgery, year of operation, type of valve substitute, periannular abscess and persistence of postoperative fever (14).

The timing of surgery is crucial to the outcome (8-10). Early surgery is performed for well documented complications of the disease process or following four to six weeks of antibiotic therapy. There is documentation that surgery performed with the onset of blood culture negativity controls the incidence of early mortality and recurrence. Early surgery under these circumstances can be performed safely with decreased hemodynamic instability and arterial embolization. The poorest outcomes of surgery are related to occurrence of renal failure and cerebral emboli, regardless of age category. The greatest risk of recurrent infection is with preoperative *Staphylococcus aureus* infective endocarditis.

The best valve substitute has had considerable attention. The allograft is recommended for complex endocarditis in the aortic position with extensive annular destruction and abscess formation (23-26). The allograft can be used as a cylinder after complete debridement of infected tissue (26). Delayed surgery for less complicated endocarditis can be performed with bioprostheses and mechanical prostheses. There has been no randomized trials comparing bioprostheses, mechanical prostheses and allografts. There is no documented difference between mechanical prostheses and bioprostheses with regard to recurrence. The long term performance of allografts and bioprostheses are similar. There is a constant risk of replacement endocarditis with the allograft. There is an initial peak risk of recurrence with other prostheses but the risk is constant by six months.

NVE

Etiology: The organisms causing NVE are similar to those that cause late PVE. The organisms are Gram-positive cocci (*Staphylococcus aureus*, *Staphylococcus epidermidis* and *Streptococcus viridans*), Gram-negative bacteria (HACEK group) and fungi (*Candida albicans* and *Aspergillus fumigatus*) (27).

Pathophysiology: Predisposing factors for NVE are cardiac abnormalities that damage endothelium by a jet injury and blood-borne microorganisms that colonize abnormal surfaces. Abnormalities of valves are caused by rheumatic valvular disease, degenerative disease or congenital abnormalities. Normal valves can also be infected depending on the virulence of the organisms. Dental procedures, endoscopic procedures and intravenous drug abuse are common causes of bacteremia and can produce endocarditis (28-31).

Diagnosis: The diagnosis of infective endocarditis is based on clinical presentation, identification of the offending organism(s) and echocardiographic findings (32,33). Doppler echocardiography is extremely useful in the diagnosis of infective endocarditis (20-22). TEE is usually better than TTE. Echocardiography can most reliably detect vegetations as small as 1 to 2 mm in native endocarditis. Echocardiography is also extremely sensitive in detecting paravalvular abscesses and cardiac fistulas.

The definitive diagnosis of infective endocarditis is best made by the appropriate combinations of major and minor criteria (simplified summary of the Duke criteria for clinical diagnosis is shown in Table 73) (34). The diagnosis of infective endocarditis is established if during a systemic infection involvement of the endocardium is demonstrated (35). If bacteremia (positive blood cultures) or bacterial DNA are found, the diagnosis is definite by culture or microbiological positive criteria (35). Endocardial involvement but culture/microbiological negative is still diagnostic of infective endocarditis (35).

Management: The predominant recommendations for surgery in NVE are provided in Table 74. The kissing vegetation of aortic valve endocarditis on the mitral valve is an indication for timely surgery to facilitate preservation of the mitral valve apparatus (36). Cerebral embolism causes a risk of secondary cerebral hemorrhage. Computed tomography is obligatory

TABLE 73
Simplified summary* of the Duke criteria for the clinical diagnosis of definite infective endocarditis

Clinical diagnosis
Two major criteria or
One major and three minor criteria or
Five minor criteria
Major criteria
Positive blood culture for infective endocarditis
Typical microorganism for infective endocarditis from two separate blood cultures
Persistently positive blood cultures
Evidence of endocardial involvement
Positive echocardiogram for infective endocarditis or patient with prosthetic heart valve must already have predisposing condition for endocarditis
New valvular regurgitation
Minor criteria
Predisposition
Predisposing heart condition or intravenous drug use
Fever ≥38.0"C
Vascular phenomena (embolic)
Immunological phenomena
Microbiological evidence
Positive blood culture but not meeting major criterion or serological evidence of active infection with organism consistent with infective endocarditis
Echocardiogram
Consistent with infective endocarditis but not meeting major criterion as noted previously

**Adapted from reference 34*

TABLE 74
Recommendations for surgery for native valve endocarditis

Indication	Class	
1. Acute aortic regurgitation or MR with heart failure	I	B
2. Acute aortic regurgitation with tachycardia and early closure of the mitral valve	I	B
3. Fungal endocarditis	I	B
4. Evidence of annular or aortic abscess, sinus or aortic true or false aneurysm	I	B
5. Evidence of valve dysfunction and persistent infection after a prolonged period (7 to 10 days) of appropriate antibiotic therapy, as indicated by presence of fever, leukocytosis and bacteremia, provided there are no noncardiac causes for infection	I	B
6. Recurrent emboli after appropriate antibiotic therapy	IIa	C
7. Infection with Gram-negative organisms or organisms with a poor response to antibiotics in patients with evidence of valve dysfunction	IIa	C
8. Mobile vegetations >10 mm	IIb	C
Contraindication		
9. Early infections of the mitral valve that can likely be repaired	III	C
10. Persistent pyrexia and leukocytosis with negative blood cultures	III	C

Criteria also apply to repaired mitral and aortic allograft or autograft valves. Endocarditis defined by clinical criteria with or without laboratory verification; there must be evidence that function of a cardiac valve is impaired. Adapted and modified from American College of Cardiology and American Heart Association Guidelines. MR Mitral regurgitation

immediately before surgery to identify early reperfusion hemorrhage. If hemorrhage is diagnosed, surgery must be postponed, if not, early surgery is recommended (37).

PVE

Etiology: PVE remains the most severe complication of valve replacement surgery. Prosthetic heart valves are a predisposing condition for endocarditis. PVE is classified as early or late. Early PVE occurs within 60 days of implantation and is likely due to a break in surgical technique or transient episodes of bacteremia from wound infections, venous catheters or postoperative pneumonia. The nosocomial origin of early PVE is due to staphylococcal organisms, Gram-negative bacilli and possibly fungi.

Late PVE occurs from bacteremia from dental procedures or infections, skin infections, abdominal infections (diverticulitis, cholecystitis) and invasive medical procedures. The organisms are streptococcal and enterococcal species.

Pathophysiology: Mechanical valvular prosthetic infections usually commence at the sewing ring or from thrombi in the vicinity of the sewing ring. Bioprosthetic infections can involve valve cusps, with or without involvement of the sewing ring. The degree of tissue necrosis appears to relate to the time of onset. Early PVE tends to be more destructive than late PVE, especially if late PVE occurs more than one year after implantation. Mortality is higher in early than late PVE.

Diagnosis: The clinical criteria for the diagnosis of PVE is essentially the same as that for NVE (a simplified summary of the Duke criteria for clinical diagnosis is shown in Table 73) (34). The echocardiographic findings of PVE include vegetations on or around the prosthetic valve; valvular dysfunction in the form of prosthetic valve stenosis, regurgitation and paravalvular leak; or perivalvular tissue invasion such as abnormal

TABLE 75
Recommendations for surgery for prosthetic valve endocarditis

Indication	Class	
1. Early prosthetic valve endocarditis (first 2 months or less after surgery)	I	B
2. Heart failure with prosthetic valve dysfunction	I	B
3. Fungal endocarditis	I	B
4. Staphylcoccal endocarditis not responding to antibiotic therapy	I	B
5. Evidence of paravalvular leak, annular or aortic abscess, sinus or aortic true or false aneurysm, fistula formation, or new-onset conduction disturbances	I	B
6. Infection with Gram-negative organisms or organisms with a poor response to antibiotics	I	B
7. Persistent bacteremia after a prolonged course (7 to 10 days) of appropriate antibiotic therapy without noncardiac causes for bacteremia	IIa	C
8. Recurrent peripheral embolus despite therapy	IIa	C
9. Vegetation of any size on or near the prosthesis	IIb	C

**Criteria exclude repaired mitral valves or aortic allograft or autograft valves. Endocarditis is defined by clinical criteria with or without laboratory verification. Adapted from American College of Cardiology and American Heart Association Guidelines*

jet lesions, abscesses and fistulas. The anterior portion of the aortic prosthesis is best examined with TTE, while the posterior aortic annulus and mitral valve are best visualized by TEE (20,22). Echocardiography provides the most information on prosthetic valve function and perivalvular anatomy with the increased incidence of *S aureus* infection early, and streptococcal infection late after surgery.

Management: Recommendations for surgery include early PVE, congestive heart failure with prosthetic valve dysfunction, fungal endocarditis, staphylococcal endocarditis not responding to antibiotic therapy, evidence of paravalvular leak, annular or aortic abscess, sinus or aortic true or false aneurysm, fistula formation or new-onset conduction disturbances, or infections with Gram-negative organisms or organisms with poor response to antibiotics (5,15,16,38) (Table 75).

The surgical treatment of choice for NVE of the mitral and tricuspid valves is reconstruction (39-44). The mitral valve can be managed with closure of perforations with glutaraldehyde — fixed autologous pericardium and posterior annular reconstruction. Tricuspid valve endocarditis can be managed by vegetectomy, valvulectomy or replacement (43,45). In conservative management, the tricuspid valve can be converted to a bicuspid valve with chordal replacement. The tricuspid valve involved with infective endocarditis can be replaced with a mitral allograft (46). Mitral and tricuspid valve sparing procedures with preservation of subvalvular apparatus and ventricular function reduces operative mortality and improves postoperative status.

NVE of the aortic valve can require extensive reconstruction for periannular abscess and fistula formation to accompanying cardiac chambers (47,48). The procedure can involve reconstruction of mitroaortic continuity, the aortoventricular junction and the RA wall with autologous pericardial patches. The total procedure requires excision of all necrotic tissue, diseased nonreparable valve and valve replacement. Aortic root abscesses with partial aortoventricular separation is best managed with allograft aortic root replacement. The fistulas between the aortic root and cardiac chambers are closed, as stated, with autologous pericardium. The LV reconstruction involves extirpation of aortic root abscess. The contiguous aorta and anterior mitral leaflet of the allograft can be used in the reparative process. Aggressive debridement of all infected and nonviable tissue, and placement of an allograft valve and root minimizes the risk of persistent infection. The options for allograft use are the scalloped, intra-aortic cylinder and allograft aortic root replacement. The infected annulus can be locally treated with phenol or iodine solution.

Alternative procedures include extra-anatomical bypass either with an apicoaortic conduit or a translocation ascending aorta prosthesis with saphenous vein coronary artery grafts. Because allografts are recommended in destructive aortic endocarditis, autografts have been reported in management of inactive, healed endocarditis.

Operations for PVE are technically demanding and time-consuming procedures. Complete debridement of all infected and necrotic tissue is necessary, following removal of the infected prosthesis. The operation must include a thorough search for subvalvular abscesses and fistula tracts. The extent of debridement determines the magnitude of the reconstruction. Aortic PVE tends to have more tissue destruction and abscess formation. Aortic PVE can erode in any direction from the sewing ring, involve the septum and anterior mitral annulus, and cause fistulas into the right atrium, left atrium and pericardium. The atrial and ventricular walls are reconstructed with autologous or bovine pericardium. The damaged annulus is replaced with the pericardium and sutured to the healthy ventricular endocardium and the anterior mitral leaflet. Abscesses are obliterated with pericardium after debridement and irrigation. If the valve substitute selected is a homograft (allograft), the attached anterior leaflet tissue is useful for closure of subvalvular abscesses and closure of perforations at the base of the native anterior mitral leaflet.

Mitral PVE can also involve the annulus. The mitral annulus can be reconstructed with autologous or bovine pericardium and the new prosthesis secured to the neoannulus. Dissociation of the atrioventricular junction during debridement is reconstructed with pericardium.

The management of active endocarditis, either native or PVE, requires accurate preoperative detection, an understanding of abscess extension, and a radical and extensive surgical approach as mandatory concepts to improve both early and long term results.

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SECTION XV: GUIDELINES FOR REPORTING MORBIDITY AND MORTALITY AFTER CARDIAC VALVULAR OPERATIONS (SOCIETY OF THORACIC SURGEONS)

The purpose of these guidelines is to facilitate the analysis and reporting of results of operations on diseased cardiac valves. The definitions and recommendations that follow are guidelines, not standards. These guidelines are designed to facilitate comparisons between the experiences of different surgeons who treat different cohorts of patients at different times with different techniques and materials.

Mortality

Thirty-day mortality (sometimes termed operative mortality) is death within 30 days of operation regardless of the patient's geographical location. Follow-up for 30-day mortality must be complete. Hospital mortality is death within any time interval after operation if the patient is not discharged from the hospital. Hospital to hospital transfer is not considered discharge; transfer to a nursing home or rehabilitation unit is considered hospital discharge unless the patient subsequently dies of complications postsurgically.

Definitions of morbidity

Structural valvular deterioration: Structural valve deterioration is any change in function (a decrease of one NYHA functional class or more) of an operated valve resulting from an intrinsic abnormality of the valve that causes stenosis or regurgitation.

Structural valvular deterioration includes operated valve dysfunction or deterioration exclusive of infection or thrombosis as determined by reoperation, autopsy or clinical investigation. The term structural deterioration refers to changes intrinsic to the valve, such as wear, fracture, poppet escape, calcification, leaflet tear, stent creep and suture line disruption of components (eg, leaflets, chordae) of an operated valve.

Nonstructural dysfunction: Nonstructural dysfunction is an abnormality resulting in stenosis or regurgitation at the operated valve that is not intrinsic to the valve itself.

Nonstructural dysfunction refers to nonstructural problems that result in dysfunction of an operated valve exclusive of thrombosis and infection diagnosed by reoperation, autopsy or clinical investigation. Examples of nonstructural dysfunction include entrapment by pannus, tissue or suture; paravalvular leak; inappropriate sizing or positioning; residual leak or obstruction from valve implantation or repair; and clinically important hemolytic anemia.

Sudden or progressive operated valvular dysfunction or deterioration may be structural, nonstructural or both, as determined by reoperation, autopsy or clinical investigation.

Valve thrombosis: Valve thrombosis is any thrombus, in the absence of infection, attached to or near an operated valve that occludes part of the blood flow path, or that interferes with the function of the valve.

Valve thrombosis may be documented by operation, autopsy or clinical investigation.

Embolism: Embolism is any embolic event that occurs in the absence of infection after the immediate perioperative period (when anesthesia-induced unconsciousness is completely reversed).

A neurological event includes any new, temporary or permanent focal or global neurological deficit. A transient ischemic attack is a fully reversible neurological event that lasts less than 24 h. A reversible ischemic neurological deficit (RIND) is a fully reversible neurological deficit that lasts more than 24 h and less than three weeks. A stroke or permanent neurological event lasts more than three weeks or causes death. Psychomotor deficits determined by specialized testing are not considered neurological events related to operated valves. Patients who do not awaken or who awaken after operation with a new stroke are excluded in tabulations of valve related morbidity.

A peripheral embolic event is an operative, autopsy or clinically documented embolus that produces symptoms from complete or partial obstruction of a peripheral (noncerebral) artery. Patients who awaken with a myocardial infarction are excluded. Patients in whom a myocardial infarction develops after the perioperative period are also excluded, unless a coronary arterial embolus is shown to be the cause of the infarction by operation, autopsy or clinical investigation. Emboli proven to consist of nonthrombotic material (eg, atherosclerosis, myxoma) are excluded.

Bleeding event (formerly anticoagulant hemorrhage): A bleeding event is any episode of major internal or external bleeding that causes death, hospitalization or permanent injury (eg, vision loss) or requires transfusion.

The 'bleeding event' complication applies to all patients, whether or not they are taking anticoagulants or antiplatelet drugs, because bleeding events can occur in patients who are not anticoagulated. Embolic stroke complicated by bleeding is classified as a neurological event under embolism and is not included as a separate bleeding event.

The warfarin anticoagulant status closest to the time that the patient suffers a valve thrombosis, embolism or bleeding event should be reported in international normalized ratio (INR) units. Whether patients were receiving a platelet inhibitory drug or not (eg, acetylsalicylic acid, dipyridamole) should also be reported.

Operated valvular endocarditis: Operated valvular endocarditis is any infection involving an operated valve.

The diagnosis of operated valvular endocarditis is based on customary clinical criteria including an appropriate combination of positive blood cultures, clinical signs or histological confirmation of endocarditis at reoperation or autopsy. Morbidity associated with active infection such as valve thrombosis, thrombotic embolus, a bleeding event or paravalvular leak, is included under this category and is not included in other categories of morbidity.

Consequences of morbid events

Reoperation: Reoperation is any operation that repairs, alters or replaces a previously operated valve.

The reasons for reoperation should be reported and may include reasons other than valve-related morbidity, such as recall, excessive noise, or incidental or prophylactic removal. Enzymatic or catheter-aided therapy of valve-related morbidity is not considered reoperation, but the morbid event that prompted the intervention should be reported.

Valve-related mortality: Valve-related mortality is death caused by structural valvular deterioration, nonstructural dysfunction, valve thrombosis, embolism, a bleeding event, operated valvular endocarditis or death related to reoperation of an operated valve. Sudden, unexplained, unexpected deaths of patients with an operated valve are included as valve-related mortality. Deaths caused by heart failure in patients with advanced myocardial disease and satisfactorily functioning cardiac valves are not included. Specific causes of valve-related deaths should be designated and reported.

Sudden unexpected, unexplained death: The cause of these deaths and the relationship to an operated valve are unknown. Therefore, these deaths should be reported as a separate category of valve-related mortality if the cause cannot be determined by clinical data or autopsy.

Cardiac death: Cardiac death includes all deaths due to cardiac causes. This category includes valve-related deaths (including sudden unexplained deaths) and nonvalve-related cardiac deaths (eg, congestive heart failure, acute myocardial infarction, documented fatal arrhythmias).

Total deaths: Total deaths are all deaths due to any cause after valve operation.

Permanent valve-related impairment: Permanent valve-related impairment is any permanent neurological or other functional deficit caused by structural valvular deterioration, nonstructural dysfunction, valve thrombosis, thrombotic embolism, a bleeding event, operated valvular endocarditis or reoperation.

Clinical valve surgery database data entry (proposed): The Society of Thoracic Surgeons National Database (STS Adult Cardiac Database Version 2.41, November 2001) and a proposed longitudinal outcomes valvular surgery module can be used for early mortality risk stratification and long term analysis of valvular surgery.

The STS has approved the concept of participant-generated software for Canadian centres contracting with the organization. The participant-generated software has been developed and has received validation by the Duke Clinical Research Institute, the warehouse of the STS National Database. The proposed longitudinal module can be incorporated into the software. This provides the opportunity for additional modules to be developed, such as a hemodynamic module. A hemodynamic module assessing aortic valve prostheses can evaluate the concept of patient-prosthesis mismatch (mean gradients, effective orifice areas, effective orifice area indexes), LV mass regression (index) in AS, and influence on survival.

The Canadian Society of Cardiac Surgeons (2001 to 2003) is exploring a partnership with the Canadian Institute of Health Information to evaluate cardiac surgery in Canada with regard to performance, resources and economics.

NYHA CLASS OF FAILURE DEFINITIONS

1. No objective evidence of limitation: Patients with cardiac disease but without resulting limitation of physical activity. Ordinary physical activity does not cause undue fatigue, palpitation, dyspnea or anginal pain.
2. Objective evidence of minimal limitation: Patients with cardiac disease resulting in slight limitation of physical activity. Comfortable at rest; ordinary physical activity results in fatigue, palpitation, dyspnea or anginal pain.
3. Objective evidence of moderately severe limitation: Patients with cardiac disease resulting in marked limitation of physical activity. Comfortable at rest; less than ordinary physical activity causes fatigue, palpitation, dyspnea or anginal pain.
4. Objective evidence of severe limitation: Patients with cardiac disease resulting in inability to carry on any physical activity without discomfort. Symptoms of heart failure or the anginal syndrome may be present even at rest. If any physical activity is undertaken, discomfort is increased.

CCVS CLASS OF ANGINA DEFINITIONS

N. No chest pain: No limitation of physical activity by pain.

1. Pain on moderate exertion: Ordinary physical activity, such as walking or climbing stairs does not cause angina. Pain with strenuous, rapid or prolonged exertion.
2. Pain limitation of normal daily activities: Comfortable at rest, but ordinary physical activity, such as walking rapidly or climbing stairs, exercise after meals, in wind or cold weather causes anginal pain.
3. Marked pain limitation of ordinary physical activity: Pain on walking on the level or climbing one flight of stairs.
4. (a) Unstable pain on any activity or rest pain: Symptom deterioration now controlled on additional oral medical therapy.

   (b) Unstable pain on any activity or rest pain: Continued pain symptoms despite maximal oral medical therapy.

   (c) Unstable pain on any activity or rest pain: Continued pain symptoms despite intravenous therapy.

The Society of Thoracic Surgeons
Adult Cardiac Surgery Database
Data Collection Form
Version 2.41

A. Administrative

Participant ID: |___|___|___|___|___| Cost Link Field: |_________________| Optional STS Trial Link Number: |___|___|___|___|___| Optional

B. Demographics

Patient Medical Record Number: _______________________ not harvested
Last Name: ____ First: _________________ MI: ____ not harvested
Date of Birth: __ __/__ __/__ __ __ __ optional harvest Age: _________ system calculation
Gender: (Male) (Female)
Race: (Caucasian) (Black) (Hispanic) (Asian) (Native American) (Other)
Social Security (or National ID) Number: _________________ not harvested
ZIP or Postal Code: _____________ optional harvest Referring Cardiologist's Name: ___________________ not harvested Referring Physician's Name: ____________________ not harvested

C. Hospitalization

Hospital Name: _____________________________ controlled list Primary Payor: _____________________________ not harvested
Date of Admission: __ __/__ __/__ __ __ __ Date of Surgery: __ __/__ __/__ __ __ __ Date of Discharge: __ __/__ __/__ __ __ __
Same Day Elective Admission: No Yes
Initial ICU Hours:_________ Readmn to ICU: No Yes ? if yes, Additional ICU Hours _________ Total Hours in ICU:___________ calculated

D. Pre-Operative Risk Factors

Weight: ___________ (kg) Height: ________ (cm)
Smoker: No Yes → if yes, Current Smoker: No Yes
Family History of CAD: No Yes
Diabetes: No Yes → if yes, select one: Diabetes Control: (None) (Diet) (Oral) (Insulin)
Hypercholesterolemia: No Yes
Last Creatinine Preop: ________
Renal Failure: No Yes → if yes, Dialysis: No Yes
Hypertension: No Yes
Cerebrovascular Accident: No Yes → if yes, When: (Recent <= 2 weeks) (Remote > 2 weeks)
Infectious Endocarditis: No Yes → If yes, Infectious Endocarditis Type: (Treated) (Active)
Chronic Lung Disease: (No) (Mild) (Moderate) (Severe)
Immunosuppressive Trtment: No Yes
Peripheral Vascular Disease: No Yes
Cerebrovascular Disease: No Yes → if yes, CVD Type: (Coma) (CVA) (RIND) (TIA) (Non Invasive > 75%) (Previous Carotid Surgery)

E. Previous Interventions

Previous CV Interventions: No Yes ? if yes, complete this section
# of Prior Cardiac Operations Requiring Cardiopulmonary Bypass: ______ # of Prior Cardiac Operations Without Cardiopulmonary Bypass: ______
Previous Surgery:
Coronary Artery Bypass: No Yes Valve: No Yes Previous Other Cardiac: No Yes
Prior PTCA including Balloon and/or Atherectomy: No Yes → if yes, Interval: <= 6 hours > 6 hours
Previous non-surgical Stent Placement: No Yes → if yes, Interval: <= 6 hours > 6 hours
Thrombolysis: No Yes → if yes, Interval: <= 6 hours > 6 hours
Previous non-surgical Balloon Valvuloplasty: No Yes

F. Pre Operative Cardiac Status

Myocardial Infarction: No Yes → if yes, When: (<= 6 hours) (> 6 hours but <24 hours) (1 - 7 days) (8 - 21 days) (> 21 days)

Congestive Heart Failure: No Yes

Angina: No Yes → if yes, Type: Stable Unstable ↓ if unstable

Unstable Type: (Rest Angina) (New Class 3) (Recent Accel) (Variant Angina) (Non-Q MI) (Post- Infarct Angina)

Cardiogenic Shock: No Yes → if yes Type: (Refractory Shock) (Hemodynamic Instability)

Resuscitation: No Yes

Arrhythmia: No Yes → if yes, Type: (Sust VT/VF) (Heart Block) (AFib/Flutter)

Classification: CCS: 0 I II III IV **NYHA**: I II III IV

G. Pre Operative Medications

Digitalis: No Yes	Beta Blockers: No Yes	Nitrates – I.V.: No Yes	Anticoagulants: No Yes	Diuretics: No Yes
Inotropic Agents: No Yes	Steroids: No Yes	Aspirin: No Yes	Ace Inhibitors: No Yes	Oth Anti-Platelets: No Yes

H. Pre Operative Hemodynamics and Cath

Number of Diseased Coronary Vessels: (None) (One) (Two) (Three)

Left Main Disease > 50%: No Yes

Ejection Fraction Done? No Yes ? if yes, Ejection Fraction: _____ → Method: (LV gram) (Radionucleotide) (Estimate) (ECHO)

Pulmonary Artery Mean Pressure Done? No Yes ? if yes, Pulmonary Artery Mean Pressure: _______

Aortic Stenosis: No Yes ? If yes, Gradient: _____ Aortic Insufficiency: 0=None 1=Trivial 2=Mild 3= Moderate 4= Severe

Mitral Stenosis: No Yes Mitral Insufficiency: 0=None 1=Trivial 2=Mild 3= Moderate 4= Severe

Tricuspid Stenosis: No Yes Tricuspid Insufficiency: 0=None 1=Trivial 2=Mild 3= Moderate 4= Severe

Pulmonic Stenosis: No Yes Pulmonic Insufficiency: 0=None 1=Trivial 2=Mild 3= Moderate 4= Severe

J. Operative

Surgeon's Name: ____________________________ controlled list Surgeon Group: _______________________________ controlled list

Status of the procedure:

Emergent Salvage

Emergent → Reason: (Shock Circ Supp) (Shock No Circ Supp) (Pulm Edema) (AEMI) (Ongoing Ischemia) (Valve Dysfnctn) (Aortic Dissection)

Urgent → Reason: (AMI) (IABP) (Worsening CP) (CHF) (Anatomy) (USA) (Rest Angina) (Valve Dysfunction) (Aortic Dissection)

Elective

Coronary Artery Bypass: No Yes (if yes, complete Section K)

Aortic:	Mitral:	Tricuspid:	Pulmonic:
No	No	No	No
Replacement	Annuloplasty only	Annuloplasty Only	Replacement
Repair/Reconstruction	Replacement	Replacement	Reconstruction
Root Reconstruction Valve Conduit	Reconstruction w/ Annuloplasty	Reconstruction w/ Annuloplasty	
Reconstruction w/ Valve Sparing	Reconstruction w/out Annuloplasty	Reconstruction w/out Annuloplasty	
Resuspension Aortic Valve		Valvectomy	
Resection Sub-Aortic Stenosis			

Other Cardiac Procedure: No Yes ↓ (if yes, complete Section N) Other Non-Cardiac Procedure: No Yes ↓ (if yes, complete Section O)

K. Coronary Surgery

Unplanned CABG: No Yes

Number of Distal Anastomoses with Arterial Conduits: _____ Number of Distal Anastomoses with Vein Grafts: ______

IMAs Used as Grafts: (Left IMA) (Right IMA) (Both IMAs) (No IMA) Number of IMA Distal Anastomoses: _______

Radial Artery(ies) Used as Grafts: (No Radial) (Left Radial) (Right Radial) (Both Radials)

Number of Radial Artery Distal Anastomoses: _______

Number of Gastro-Epiploic Artery Distal Anastomoses: _______

 2 Adult Cardiac Data Collection Form (Version 2.41)

L. Valve Surgery

↓ Key M = Mechanical, B = Bioprosthesis, H = Homograft, A = Autograft, R = Ring

Aortic Prosthesis -	Implant Type:	None M B H A R	Implant: ________________	Size: _____(mm)
	Explant Type:	None M B H A R	Explant: ________________	Size: _____(mm)
Mitral Prosthesis -	Implant Type:	None M B H A R	Implant: ________________	Size: _____(mm)
	Explant Type:	None M B H A R	Explant: ________________	Size: _____(mm)
Tricuspid Prosthesis -	Implant Type:	None M B H A R	Implant: ________________	Size: _____(mm)
	Explant Type:	None M B H A R	Explant: ________________	Size: _____(mm)
Pulmonic Prosthesis -	Implant Type:	None M B H A R	Implant: ________________	Size: _____(mm)
	Explant Type:	None M B H A R	Explant: ________________	Size: _____(mm)

Valve Key

Mechanical
M1= ATS Mechanical Prosthesis
M2= Björk-Shiley Convex-Concave Mechanical Prosthesis
M3= Björk-Shiley Monostrut Mechanical Prosthesis
M4= CarboMedics Mechanical Prosthesis
M5= Edwards Tekn a Mechanical Prosthesis
M6= Lillehei-Kaster Mechanical Prosthesis
M7= Medtronic-Hall Mechanical Prosthesis
M8= OmniCarbon Mechanical Prosthesis
M9= OmniScience Mechanical Prosthesis
M10= On-X Mechanical Prosthesis
M11= Sorin Bicarbon (Baxter Mira) Mechanical Prosthesis
M12= Sorin Monoleaflet Allcarbon Mechanical Prosthesis
M13= St. Jude Medical Mechanical Prosthesis
M14= Starr-Edwards Caged-Ball Prosthesis
M15= Ultracor Mechanical Prosthesis

Bioprosthetic
B1= Baxter Prima Plus Stentless Porcine Bioprosthesis
B2= Baxter Prima Stentless Porcine Bioprosthesis
B3= Biocor Porcine Bioprosthesis
B4= Biocor Stentless Porcine Bioprosthesis
B5= CarboMedics PhotoFix Pericardial Bioprosthesis
B6= Carpentier-Edwards Pericardial Bioprosthesis
B7= Carpentier-Edwards Standard Porcine Bioprosthesis
B8= Carpentier-Edwards Supra-Annular Porcine Bioprosthesis
B9= Cryolife O'Brien Stentless Porcine Bioprosthesis
B10= Hancock Standard Porcine Bioprosthesis
B11= Hancock II Porcine Bioprosthesis
B12= Hancock Modified Orifice Porcine Bioprosthesis
B13= Ionescu-Shiley Pericardial Bioprosthesis
B14= Labcor Stented Porcine Bioprosthesis
B15= Labcor Stentless Porcine Bioprosthesis
B16= Medtronic Freestyle Stentless Porcine Bioprosthesis
B17= Medtronic Intact Porcine Bioprosthesis
B18= Medtronic Mosaic Porcine Bioprosthesis
B19= Mitroflow Pericardial Bioprosthesis
B20= Sorin Pericarbon Stentless Pericardial Bioprosthesis
B21= St. Jude Medical - Toronto SPV Stentless Porcine Bioprosthesis
B22= St. Jude Medical -Bioimplant Porcine Bioprosthesis

Homograft
H1= Homograft Aortic – Subcoronary
H2= Homograft Aortic Root/Cylinder
H3= Homograft Mitral
H4= Homograft Pulmonic Root
H5= Cryolife Homograft

Autograft
A1= Autograft Pulmonic Root

Ring
R1= Carpentier-Edwards Classic Ring
R2= Carpentier-Edwards Physio Ring
R3= Cosgrove-Edwards Ring
R4= Medtronic Sculptor Ring
R5= Medtronic-Duran Ring
R6= Sorin-Puig-Messana Ring
R7= St. Jude Medical Sequin Ring

777= Other

M. Operative Techniques

Cardiopulmonary Bypass Used: No Yes → if yes, Conversion to CPB: No Yes

Primary Indication for minimally Invasive approach: (not minimally invasive) (Surg/Pat Choice) (Contraindicated Std Approach) (Comb Cath Intervention)

Primary Incision:

Full Sternotomy Partial Sternotomy Transverse Sternotomy Right Vertical Parasternal Left Vertical Parasternal

Right Anterior Thoracotomy Left Anterior Thoracotomy Posterolateral Thoracotomy Xiphoid Epigastric Subcostal

Total # of Incisions: ______ Conversion to Stnd Incision: (not minimally invasive) No Yes → if yes, Indication: (not minimally invasive) (Exposure) (Bleeding) (Rhythm) (Hypotension) (Conduit)

Cannulation Meth: (None) (Aorta and Fem/Jug Vein) (Fem Art and Fem/Jug Vein) (Aorta and Atrial/Caval) (Fem Art and Atrial/Caval) (Other)

Aortic Occlusion Method: (None) (Cross-clamp) (Balloon Occlusion)

Intracoronary Shunt used during distal anastomoses: No Yes

Suture Technique: (Running) (Interrupted) (Stapler) (Combination)

Vessel Stabilization Technique: (None) (Suture Snare) (Suction Device) (Compression) (Other)

IMA Harvest Technique: (None) (Direct Vision) (Thoracoscopy) (Combination)

Acute Flow Patency Assess of Grafts (Periop): (None) (IntaOp Doppler) (IntraOp Angio) ()Postop Angio) (Postop Doppler)

N. Other Cardiac Procedures

No Yes Left Ventricular Aneurysm Repair	No Yes Vent Septal Defect Repair	No Yes Atrial Septal Defect Repair
No Yes Batista	No Yes SVR	No Yes Congenital Defect Repair
No Yes Transmyocard Laser Revasc	No Yes Cardiac Trauma	No Yes Cardiac Transplant
No Yes Permanent Pacemaker	No Yes AICD	No Yes Other

O. Other Non Cardiac Procedures

No Yes Aortic Aneurysm   No Yes Carotid Endarterectomy   No Yes Other Vascular   No Yes Other Thoracic

P. CPB and Support

Skin Incision Start Time: ________ 24 hour clock   Skin Incision Stop Time: _______ 24 hour clock

Cross Clamp Time (min): ________   Perfusion Time (min): _________   Cardioplegia: No Yes

IABP No Yes → if yes, When Inserted: (Preop) (Intraop) (Postop)

If yes, ? Indication: (Hemodynamic Instab) (PTCA Support) (Unst. Angina) (CPB Wean) (Prophylatic)

Ventricular Assist Device: No Yes

Q. Post Operative

Blood Products Used: No Yes

Initial # of Hrs Ventilated Postop: _______   Re-intubated During Hosp Stay: No Yes ? if yes, Addl Hours Ventilated Postop: _________

Total Hours Ventilated Postop: _______

R. Complications   In hospital Complications: No Yes ? if yes, at least one complication below must be selected

Operative	No Yes ReOp for Bleeding/Tamponade	Infection	No Yes Sternum – Deep
	No Yes ReOp for Valvular Dysfunction		No Yes Thoracotomy
	No Yes ReOp for Graft Occlusion		No Yes Leg
	No Yes ReOp for Other Cardiac Problem		No Yes Septicemia
	No Yes ReOp for Other Non Cardiac Problem		No Yes Urinary Tract Infection
	No Yes Perioperative Myocardial Infarction		
Neurologic	No Yes Stroke	Pulmonary	No Yes Prolonged Ventilation
	No Yes Transient		No Yes Pulmonary Embolism
	No Yes Continuous Coma >=24Hrs		No Yes Pneumonia
Renal	No Yes Renal Failure	Vascular	No Yes Vascular - Aortic Dissection
	No Yes Dialysis		No Yes Illiac/Femoral Dissection
			No Yes Acute Limb Ischemia
Other	No Yes Heart Block		
	No Yes Cardiac Arrest		No Yes Gastro-Intestinal Complication
	No Yes Anticoagulant Complication		No Yes Multi-System Failure
	No Yes Tamponade		No Yes Atrial Fibrillation

S. Discharge (Note: this section is blank if patient dies during initial hospital stay)

Aspirin: No Yes | Ace-Inhibitors: No Yes | Beta Blockers: No Yes | Lipid Lowering: No Yes | Other Anti-Platelets: No Yes

Discharge Location: (Home) (Extended Care/TCU) (Other Hospital) (Nursing Home) (Other)

T. Mortality

Mortality - Mortality: No Yes   Discharge Status: Alive Dead   Status at 30 days after surgery: Alive Dead

Mortality - Operative Death: No Yes   Mortality - Date __ __/__ __/__ __ __ __ (mm/dd/yyyy)

Location of Death: (OR) (Hospital) (Home) (Other Facility)

Primary Cause of Death (select only one): (Cardiac) (Neurological) (Renal) (Vascular) (Infection) (Pulmonary) (Valvular) (Other)

U. Readmission (Note: this section is blank if patient dies during initial hospital stay)

Readmit <=30 Days from Date of Procedure: No Yes↓ if yes, select the most predominate reason

Readmission Reason:

(Anticoagulant Complications)	(Arrhythmias/Heart Block/Pacemaker Insertion/AICD)	(CHF)
(MI/Recurrent Angina)	(Pericardial Effusion/Tamponade)	(Pneumonia/ Respiratory Complication)
(Valve Dysfunction)	(Infection Deep Sternum)	(Infection Leg)
(Cardiac Cath)	(PTCA Stent)	(Renal Failure)
(TIA)	(Reop for Graft Occlusion)	(Reop for Bleeding)
(Permanent CVA)	(Acute Vascular Complication)	(Other)

LONGITUDINAL OUTCOMES – VALVULAR SURGERY

Date of Follow-up: _ _ / _ _ / _ _ _ _
mo dd year

VALVULAR

Status (None M B H A R) **Aortic:** **Mitral:** **Tricuspid:** **Pulmonary**:

Procedure (alternative centre) since Position: Type: Prosthesis:

Date: _ _ / _ _ / _ _ _ _
mo dd year

Classification: CCS 0 1 2 3 4 **NYHA** : 1 2 3 4

Other Procedure (alternative centre) since **Coronary Surgery**: No Yes (Refer K)
Date: _ _ / _ _ / _ _ _ _
mo dd year

Other Cardiac: No Yes (Refer N)
Date: _ _ / _ _ / _ _ _ _
mo dd year

Rhythm: **At Fib**: No Yes **NSR**: No Yes **Permanent Pacemaker**: No Yes

Medications:

Aspirin: No Yes **Ace Inhibitors**: No Yes **Beta Blockers:** No Yes

Lipid Lowering: No Yes **Other Anti-Platelet**: No Yes **Anticoagulants**: No Yes

Digitalis: No Yes **Inotropic Agents**: No Yes **Diuretics**: No Yes

Complications:

Valve-Related (Positional) A M T P (Replace/Repair)

Etiology: **SVD**: No Yes **NSD**: No Yes **Thrombosis**: No Yes
PVE: No Yes
Date positional: _ _ / _ _ / _ _ _ _
mo dd year

Valve-Related (Systemic)

Etiology: **TE**: No Yes **Major**: No Yes **Minor**: No Yes
RIND: No Yes **Bleeding**: No Yes

Date systemic: _ _ / _ _ / _ _ _ _
mo dd year

Anticoagulant Status (Closest to event) INR: ………………………..

Composites of Complications:

Valve-Related Reoperation: No Yes Date: _ _ / _ _ / _ _ _ _
mo dd year

Cause: **SVD** No Yes **NSD**: No Yes **PVE**: No Yes
Thrombosis: No Yes

Valve-Related Morbidity: No Yes Date: _ _ / _ _ / _ _ _ _
mo dd year

Cause: SVD No Yes **NSD**: No Yes **TE**: No Yes
Thrombosis: No Yes **Bleeding**: No Yes **PVE**: No Yes
REOP: No Yes

Valve-Related Mortality: No Yes Date: _ _ / _ _ / _ _ _ _
mo dd year

Cause: SVD No Yes **NSD**: No Yes **TE**: No Yes
Thrombosis: No Yes **Bleeding**: No Yes **PVE**: No Yes
REOP: No Yes **Sudden, unexplained, unexpected:** No Yes

Mortality (Refer T)

PROSTHETIC HEART VALVES: PROTOCOL FOR EVALUATION OF EXPLANTED DEVICES

1) Patient Information

Name: ___ Hospital #: ______________________________

Age: _____ Year: _____ Sex: M / F Pathology #: ______________________________

Location of Prosthesis: ______________________________

Reason for Implantation: ______________________________

Date of Implantation: ______________________________

Reason for Explantation: (a) Prosthesis Related ________ (b) Patient Related ________

Date of Explantation: ______________________________

Duration of Implant: ______________________________

Type of Prosthesis: ______________________________

Manufacturer: ____________________ Model: ______________________________

NB: (1) Specimen should be fixed in appropriate medium.

(2) Specimen must be handled with latex gloves at all times.

2) Device Details

Gross Examination: ______________________________

Site from which Explanted: ______________________________

Type of Prosthesis:

(a) Bioprosthesis:(1) Porcine __ (2) Pericardial __ (3)Homograft ___ (4) Autograft___

(b) Mechanical:

Name:________________ Model #:____________ Serial # (if available): ____________

Measure and Record Appropriate Dimensions: ______________________________

Appearance: ______________________ Deformation: ______________________________

(a) Operative: ______________________________

(b) Stent Deformation in vivo: ______________________________

Changes as Compared to Pre-Implant Device: ______________________________

Consistency of Biological Tissues: ______________________________

(a) Hardening (Mineralization): ______________________________

(b) Tears *(note location):* ______________________________

(c) Prolapse of Tissues: ______________________________

(d) Vegetations / Thrombus: ____________________

(e) Pannus *(note thickness and extension onto the sewing ring and cusps):* __________

Radiological Examination** (2 Planes, at least) **in a Faxitron

1) Manufacturer, Device, Model #, etc: ____________________

2) Materials Damage: ____________________

(a) Number of Components: ____________________

(b) Loss of Parts of Device: ____________________

(c) Deposition of Minerals: ____________________

(d) Integrity of Device: ____________________

Prosthetic Heart Valves

Gross: Type of Prosthesis

1) Bioprosthesis:

Porcine: ______ Hancock I
Hancock II
Hancock MO
Medtronic Mosaic
Medtronic Intact
Carpentier-Edwards Standard
Carpentier-Edwards Supra-Annular

Pericardial: ______ Carpentier-Edwards PERIMOUNT
Mitroflow Synergy

Other: ______ Name of Device: __________________

2) Mechanical:

1) Ball in Cage: Starr-Edwards ____________________

2) Tilting Disc: ____________________

(a) Bjork-Shiley ____________________

(b) Medtronic Hall ____________________

3) Bileaflet: ____________________

(a) St. Jude Medical: Standard ____________ or Masters-Silzone ______________

(b) CarboMedics ____________________

(c) Edwards-Mira ____________________

(d) On-X ____________________

(e) ATS ____________________

4) Investigational Devices ____________________

3) Pericardial (ISLP and Hancock Discontinued): ______________________

4) Stentless: ______________________
   1) T-SPV (St. Jude Medical) ______________________
   2) Freestyle (Medtronic) ______________________
   3) Prima Plus(Edwards) ______________________

5) Homografts / Allografts: ______________________

6) Autograft Valve (Ross Procedure): ______________________

X-Ray: Mineralization

Grade: 0 _______ 1+ _______ 2+ _______ 3+ _______ 4+ _______

Location: ______________________

Measure Size of Effective Orifice: (2 Planes) ______________________

Mechanical: ______________________
   1) Components: ______________________
      (a) Intact ______________________
      (b) Deficient ______________________
   2) Occluder Movement: ______________________
   3) Thrombi / Vegetations: ______________________
   4) Symmetry: ______________________
   5) Attached Tissues (Pannus, MV Leaflet): ______________________
   6) Surface of Materials: ______________________

Bioprostheses: ______________________

Measure Size of Each of 3 Cusps: ______________________
   1) Cusp Tears: Number _______ Location _____________ Type _____________
   2) Cusp Prolapse: ______________________
   3) Cusp Redundancy: ______________________
   4) Pannus: _____________ Location: _____________
      (a) Flow Surface ______________________
      (b) Non-Flow Surface ______________________

5) Cusp Consistency (Pliability): ____________________
6) Stent Posts: ____________________
7) Thrombus: ____________________

Specimen Photography

1) Photograph both surfaces of device: ____________________
2) Photograph after removal of attached tissue: ____________________
3) Photograph close up areas of concern: ____________________

Microscopy

7. Bioprosthesis: Sections as required ____________________
   1) Longitudinal Mid Cusp: ____________________
   2) Include Tear (Horizontal section if necessary): ____________________
   Record the Orientation and Location of Cut Tissues: ____________________
   (Stains: H & E, Gram, Von Kossa, Other)
   Analyze Section for: ____________________
   (Stains: H & E, Gram, Von Kossa, Other)
   (a) Tissue Degeneration ____________________
   (b) Fluid Insudation ____________________
   (c) Mineralization ____________________
   (d) Infection ____________________
   (e) Pannus ____________________

8. Mechanical Prosthesis
   Sections of: ____________________
   1) Pannus and Underlying Sewing Ring ____________________
   2) Thrombus / Vegetation ____________________
   3) Fabric Sewing Ring ____________________

Diagnosis: ____

____

____

Comments: Summarize findings and correlate with clinical features.

____

____

____

NB: 1) Explanted Prostheses (Mitral / Tricuspid Site)

(a) Look for attached native valve leaflet tissue (Native valve conserving procedure)

(b) Look for pannus in adjacent parts of prosthesis

2) Excised Native Valves

(a) Look for artificial chordae (within a few months of procedure these become indistinguishable from native chordae, history therefore is essential)

(i) Photograph Specimen

(ii) Take Sections Transverse

(b) Native Valve Repair

(i) Mitral: Photograph

Take Sections usually longitudinal; may need decalcification

(ii) Aortic: Photography

Take Sections transverse at commissure; longitudinal across cusp

3) Patient Related Explantation

(i) Concomitant Surgery

(ii) Paravalvular Leak

(iii) Hemolysis / Anemia

(iv) Disposition

(v) Long Suture Tail / Entrapment

Simplified summary of the Duke criteria for the clinical diagnosis of definite infective endocarditis

Clinical diagnosis

Two major criteria or
Two major and three minor criteria or
Five minor criteria

Major criteria

Positive blood culture for infective endocarditis
- Typical microorganism for infective endocarditis from two separate blood cultures
- Persistently positive blood cultures

Evidence of endocardial involvement
- Positive echocardiogram for infective endocarditis or new valvular regurgitation

Minor criteria

Predisposition
- Predisposing heart condition or intravenous drug use
  - Fever: ≥38.0 C
  - Vascular phenomena
  - Immunological phenomena

Microbiological evidence
- Positive blood culture but not meeting major criterion or serological evidence of active infection with organism consistent with infective endocarditis

Echocardiogram
Consistent with infective endocarditis but not meeting major criterion as noted previously

**Durack DT, Lukes AS, Bright DK. New criteria for diagnosis of infective endocarditis utilization of specific echocardiographic findings. The Duke Endocarditis Series. Am J Med 1994;96:200*

Cardiac conditions associated with endocarditis

Endocarditis prophylaxis recommended

High-risk category
- Prosthetic cardiac valves, including bioprosthetic and homograft valves
- Previous bacterial endocarditis
- Complex cyanotic congenital heart disease (eg, single ventricle states, transposition of the great arteries, Tetralogy of Fallot)
- Surgically constructed systemic-pulmonary shunts or conduits

Moderate-risk category
- Most other congenital cardiac malformations (other than above and below)
- Acquired valvular dysfunction (eg, rheumatic heart disease)
- Hypertrophic cardiomyopathy
- Mitral valve prolapse with valvular regurgitation and/or thickened leaflets*

Endocarditis prophylaxis not recommended

Negligible-risk category (no greater risk than the general population)
- Isolated secundum atrial septal defect
- Surgical repair of atrial septal defect, ventricular septal defect, or patent ductus arteriosus (without residual beyond 6 months)
- Previous coronary artery bypass graft surgery
- Mitral valve prolapse without valvular regurgitation*
- Physiological, functional, or innocent heart murmurs*
- Previous Kawasaki disease without valvular dysfunction
- Previous rheumatic fever without valvular dysfunction
- Cardiac pacemakers (intravascular and epicardial) and implanted defibrillators

**AHA Scientific Statement B Recommendations by the American Heart Association*

Prophylactic regimens for endocarditis prevention

Dental procedures: prophylaxis recommended*
Dental extractions
Periodontal procedures including surgery, scaling and root planing, probing and recall maintenance
Dental implant placement and reimplantation of avulsed teeth
Endodontic (root canal) instrumentation or surgery only beyond the apex
Subgingival placement of antibiotic fibres or strips
Initial placement of orthodontic bands but not brackets
Intraligamentary local anesthetic injections
Prophylactic cleaning of teeth or implants where bleeding is anticipated
Dental procedures: prophylaxis not recommended
Restorative dentistry (operative and prosthodontic) with or without retraction cord
Local anesthetic injections (nonintraligamentary)
Intracanal endodontic treatment; post placement and buildup
Placement of rubber dams
Postoperative suture removal
Placement of removable prosthodontic or orthodontic appliances
Taking of oral impressions
Fluoride treatments
Taking of oral radiographs
Orthodontic appliance adjustment
Shedding of primary teeth
Other procedures: prophylaxis recommended
Respiratory tract
Tonsillectomy or adenoidectomy
Surgical operations that involve respiratory mucosa
Bronchoscopy with a rigid bronchoscope
Gastrointestinal tract
Sclerotherapy for esophageal varices
Esophageal stricture dilation
Endoscopic retrograde cholangiography with biliary obstruction
Biliary tract surgery
Surgical operations that involve intestinal mucosa
Genitourinary tract
Prostatic surgery
Cystoscopy
Urethral dilation
Other procedures: prophylaxis not recommendeded
Respiratory tract
Endotracheal intubation
Bronchoscopy with a flexible bronchoscope, with or without biopsy
Tympanostomy tube insertion
Gastrointestinal tract
Transesophageal echocardiography
Endoscopy with or without gastrointestinal biopsy
Genitourinary tract
Vaginal hysterectomy
Vaginal delivery
Cesarean section
In uninfected tissue: Urethral catheterization, uterine dilation and curettage, therapeutic abortion, sterilization procedures, insertion or removal of intrauterine devices
Other
Cardiac catheterization, including balloon angioplasty
Implanted cardiac pacemakers, implanted defibrillators and coronary stents
Incision or biopsy of surgically scrubbed skin
Circumcision

**Prophylaxis is recommended for patients with high- and moderate-risk cardiac conditions. This includes restoration of decayed teeth (filling cavities) and replacement of missing teeth. Clinical judgment may indicate antibiotic use in selected circumstances that may create significant bleeding. AHA Scientific Statement Recommendations by the American Heart Association. Prophylaxis is recommended for high-risk patients. It is optional for medium-risk patients. Prophylaxis is optional for high-risk patients. AHA Statement Recommendations by the American Heart Association*

Prophylactic regimens for dental, oral, respiratory tract or esophageal procedures

Situation	Agent	Regimen
Standard general prophylaxis	Amoxicillin	Adults: 2.0 g; children: 50 mg/kg orally 1 h before procedure
Unable to take oral medications	Ampicillin	Adults: 2.0 g IM or IV children: 50 mg/kg IM or IV within 30 min before procedure
Allergic to penicillin	Clindamycin,	Adults: 600 mg; children: 20 mg/kg orally 1 h before procedure
	cephalexin, cefadroxil,	Adults: 2.0 g; children: 50 mg/kgorally 1 h before procedure
	azithromycin or clarithromycin	Adults: 500 mg; children: 15 mg/kg orally 1 h before procedure
Allergic to penicillin and unable	Clindamycin or	Adults: 600 mg; children: 20 mg/kg IV within 30 min before procedure
to take oral medications	cefazolin	Adults: 1.0 g; children: 25 mg/kg IM or IV within 30 min before procedure

Total children s dose should not exceed adult dose. Cephalosporins should not be used in individuals with immediate-type hypersensitivity reaction (urticaria, angioedema or anaphylaxis) to penicillins. AHA Scientific Statement Recommendations by the American Heart Association. IM Intramuscular; IV Intravenous

Prophylactic regimens for genitourinary or gastrointestinal (excluding esophageal) procedures

Situation	Agent	Regimen
High-risk patients	Ampicillin plus gentamicin	Adults: ampicillin 2.0 g IM or IV plus gentamicin 1.5 mg/kg (not to exceed 120 mg) within 30 min of starting procedure; 6 h later, ampicillin 1 g IM/IV or amoxicillin 1 g orally
		Children: ampicillin 50 mg/kg IM or IV (not to exceed 2.0 g) plus gentamicin 1.5 mg/kg within 30 min of starting the procedure; 6 h later, ampicillin 25 mg/kg IM/IV or amoxicillin 25 mg/kg orally
High-risk patients allergic to ampicillin/amoxicillin	Vancomycin plus gentamicin	Adults: vancomycin 1.0 g IV over 1 to 2 h plus gentamicin 1.5 mg/kg IV/IM (not to exceed 120 mg); complete injection/infusion within 30 min of starting procedure
		Children: vancomycin 20 mg/kg over 1 to 2 h plus gentamicin 1.5 mg/kg IV/IM; complete injection/ infusion within 30 min of starting procedure
Moderate-risk patients	Amoxicillin or ampicillin	Adults: amoxicillin 2.0 g orally 1 h before procedure, or ampicillin 2.0 g IM/IV within 30 min of starting procedure
		Children: amoxicillin 50 mg/kg orally 1 h before procedure, or ampicillin 50 mg/kg IM/IV within 30 min of starting procedure
Moderate-risk patients allergic to ampicillin/amoxicillin	Vancomycin	Adults: vancomycin 1.0 g IV over 1 to 2 h; complete infusion within 30 min of starting procedure
		Children: vancomycin 20 mg/kg IV over 1 to 2 h; complete infusion within 30 min of starting procedure

Total children s dose should not exceed adult dose. No second dose of vancomycin or gentamicin is recommended. AHA Scientific Statement Recommendations by the American Heart Association. IM Intramuscular; IV Intravenous