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Essentials of Operative Cardiac Surgery

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Preface

> You cannot open a book without learning something. Confucious (551–479 BC) – Chinese teacher, editor, politician and philosopher

Heart disease is a major health problem in the world and heart surgery is now common for revascularisation in coronary artery disease, heart valve repair and replacements and heart and heart lung transplantation.

In England, in the NHS, annually approximately 22,000–24,000 coronary artery bypass graft (CABG) operations and just over 11,000 valve procedures are performed. Whereas the number of CABGs performed has been approximately the same in recent years, valve surgery is increasing by about 5–10% every year. There is a general trend to more minimally invasive surgery and some surgeons are now using off-pump surgery techniques. Currently, it is estimated that more than one million cardiac operations are performed each year worldwide with use of the heart-lung machine. In most cases, the operative mortality is quite low, approaching 1% for some operations [1].

Motivated by a desire to simplify the mystique of cardiac surgery, the goal of this book is to aid surgeons in mastering the skills necessary in an ever-expanding field of cardiac surgery. This book is an amalgamation of the surgical principles, tips and tricks.

The Philosophy of *Essentials of Operative Cardiac Surgery* is to keep simple cases simple and turn complex cases into simple cases.

Live as if you were to die tomorrow. Learn as if you were to live forever. M K Gandhi (1869–1948), leader of India's independence movement.

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Reference

1. Punjabi PP, Taylor KM. The science and practice of cardiopulmonary bypass: from cross circulation to ECMO and SIRS. Global Cardiol Sci Pract. 2013:32.

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Chapter 1
Echocardiography in Cardiac Surgery

Zivile Valuckiene and Petros Nihoyannopoulos

Introduction

Echocardiography is a widely used non-invasive imaging modality which provides real-time dynamic information on cardiac structures of interest. Transoesophageal echocardiography (TOE) is remarkable for its superior image quality and has served the cardiac surgeons in the perioperative setting since the 1980s. Its initial role was monitoring of left ventricular (LV) function, which, over time has expanded to encompass the complex assessment of the anatomy and function of all heart chambers, valves and the great vessels [1]. Introduction of real time three dimensional (3D) echocardiography has made a revolutionised the history of echocardiography by transforming it into a highly competitive and comprehensive imaging modality.

Transthoracic echocardiographic (TTE) assessment is routinely performed before any cardiac surgical procedure. Preoperative TOE is recommended when TTE is non-diagnostic or more detailed evaluation of cardiac structures is needed. TOE has also secured its place in the perioperative setting and is recommend in:

- All open heart (valvular) and thoracic aortic surgical procedures;
- Some (high risk) coronary artery bypass graft cases;

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- Non-cardiac surgery when patients have known or suspected cardiovascular pathology which may negatively impact outcomes [2].

Standard Echocardiographic Assessment

Comprehensive echocardiographic assessment provides a surgeon with information on cardiac chambers, valves and the great vessels. In this chapter, we will highlight the applications of echocardiography on the following topics, most relevant for cardiothoracic surgeons:

Left ventricular (LV) function assessment
Right ventricular (RV) function assessment
Mitral valve (MV) assessment
Aortic valve assessment
Prosthetic valves
Myectomy
Postoperative Complications

LV Function Assessment

Evaluation of LV function is essential for the preoperative assessment of the patient. The degree of LV impairment and dilatation are important parameters when timing valvular surgery. Quick 'eyeballing' of the overall systolic function by an experienced observer in the operating room is a good correlate to quantitative measurements of LV ejection fraction which is performed by the Simpson method or recently introduced 3D LV volumetric reconstruction (Fig. 1.1). Assessment of LV regional wall motion abnormalities (RWMA) allows detection of areas of myocardial asynergy and identifies coronary territories in compromise. New RWMA in the perioperative setting may indicate native coronary artery (accidental ligation) or early graft failure, inadequate myocardial preservation during cardioplegia or off-pump surgery. This is particularly important in the right coronary artery territory as, due to its anterior and superior location, air embolism may

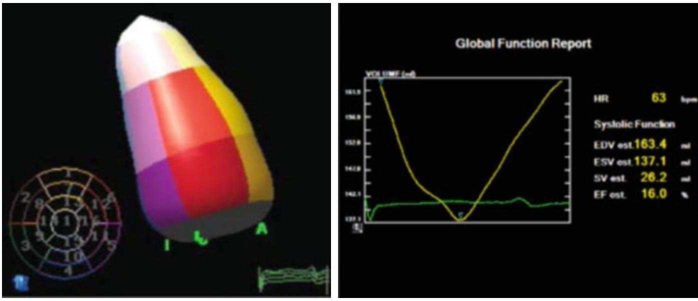

FIGURE 1.1 Left ventricular volume and ejection fraction assessment by three-dimensional reconstruction on transthoracic echocardiography. There is evident left ventricular dilatation (end-diastolic and end-systolic volumes are 163 ml and 137 ml, respectively) and severely reduced global left ventricular systolic function (EF 16 %). A semiautomatic algorithm assesses both global (EF) as well as regional LV volumes with the LV segmented into 16 regions (colour coding of the LV)

occur. Occasionally, the left circumflex artery (supplying blood to the lateral wall) may become compromised as there is a risk of accidental ligation of the artery in the atrioventricular groove while applying sutures in the posterior mitral annular area. TOE assists the surgeon while weaning-off the patient from cardiopulmonary bypass (CPB) and helps ensure complete de-airing of the cardiac chambers by providing visualisation of residual air bubbles in the LV cavity, thus, reducing the risk of coronary air embolism and subsequent RV or LV dysfunction. Perioperative LV dimensions help to assess systemic volume status. While assessing the LV function in the operating room, it is useful to take the following tips into consideration:

- CPB unloads both ventricles and LV function may appear better than it really is;
- Systemic volume underfilling status may falsely 'shrink' the LV;
- At a slow heart rate, the LV appears 'sluggish' and the increase in heart rate may improve the systolic function in such case;

- Paradoxical anterior systolic motion of the interventricular septum is a common finding after pericardiotomy and, when observed in isolation, does not indicate new myocardial ischemia.

To avoid possible pitfalls in LV assessment, its volumes and function should be assessed, not only while coming off bypass, but also at the very end of the surgery (fully off-bypass).

RV Function

Right ventricular (RV) function is of particular concern, both before and after CPB surgery. Poor RV function may preclude the patients from undergoing any surgical procedure requiring general anaesthesia (GA) and CPB. The thin walls and crescent shape of the RV make it a highly compliant chamber, able to accommodate significant increases in volume; however, the ability to comply with a significant increase in pressure is limited. Decreased RV function is a recognized phenomenon after CPB and is associated with increased mortality rates [3]. It is important to recognize RV dilatation and free wall hypokinesis, which frequently occur post CPB; however, transient RV stunning needs to be distinguished from ongoing or established ischaemia that may hamper weaning-off the patient from CPB. The assessment of RV function in theatre is highly subjective and experienced operators are needed.

From the transthoracic approach, several parameters have been described to assess RV function (see recent ASE/EACVI guidelines [4]). Among many suggested quantitative parameters, tricuspid annular plane systolic excursion (TAPSE) is by far the most validated and easy to use at the echocardiography department or in a busy intraoperative theatre setting (Fig. 1.2). Current guidelines suggest the degree of RV systolic impairment is present when TAPSE is 16 mm or less. The assessment of RV function goes hand in hand with pulmonary artery (PA) pressure estimates. PA pressure is easily obtainable by echocardiography if there is a sufficient degree of measurable tricuspid regurgitation (TR). However, this measurement is unreliable in cases of severe TR. Evidence

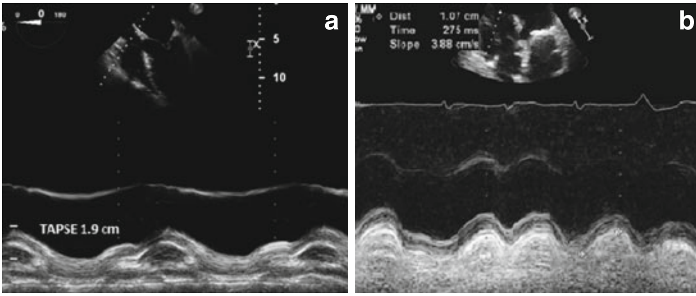

FIGURE 1.2 (**a**) Normal (TAPSE 1.9 cm) obtained by transoesophageal echocardiography in mid-oesophageal 4 chamber view (note the difficulty in axial alignment of the cursor in this view, contributing to underestimation of measured parameters). (**b**) Impaired right ventricle as evidenced by moderately reduced TAPSE (1.07 cm) measured on TTE

of RV failure, the presence of pulmonary arterial hypertension (PAH) and CPB is a 'killer combination', notorious for extremely high surgical risk. Therefore, RV dimensions, function (TAPSE) and PA systolic pressures should be carefully assessed before any open heart surgery.

Perioperative TOE allows prompt assessment of RV morphology and volume loading conditions. The interventricular septum becomes flattened during diastole in acute RV distension due to volume overload of the RV. Acute RV dilation shifts the interventricular septum towards the LV, resulting in LV compression, underfilling and reduced systemic cardiac output, leading to weaning-off CPB difficulties. Persistently hypokinetic RV and a small hyperdynamic LV cavity may direct the surgical team towards insertion of a RV assist device if adequate therapeutic support is ineffective.

Valve Assessment

Valvular function should be carefully evaluated for every patient as part of a standard preoperative assessment. If there is a valvular issue, it needs to be clarified before the surgery.

Preoperative TOE may be needed if TTE is inconclusive. In valvular assessment, perioperative echocardiography is constrained by the following limitations:

- *Altered haemodynamic and loading conditions*: reduced preload and afterload of the ventricles under GA accounts for substantially less valvular regurgitation in comparison to preoperative evaluation;
- *Risk of heart rate and rhythm alterations*: reduced systemic blood pressure under GA causes reflective tachycardia and general anaesthetics may provoke atrial fibrillation, consequently, the estimation of valvular lesions may be difficult;
- *Reduced capacity to work up complex valve lesions*: in a busy operating room, the time span for echocardiographic examination may be limited and, under altered LV loading conditions, the assessment of the pathology may not be straightforward.

No valvular case should be accepted to theatre without a high quality preoperative echocardiographic assessment and full understanding of the underlying pathology.

Mitral Valve (MV) Assessment

Anatomy

The mitral apparatus is a complex structure, composed from mitral annulus, two leaflets, chordae and two papillary muscles. The mitral annulus is a frequent surgical target in cardiac surgery and its unique saddle-shaped anatomy was first understood by the help of 3D echocardiography [4] (Fig. 1.3). Carpentier's classification of mitral leaflet segments has been widely adopted and used in practice. Each of the two mitral valve leaflets are divided into 3 equal thirds, thus, avoiding the individual anatomic variations of the number and size of the leaflet scallops (Fig. 1.4). It also enables better communication among the cardiac sonographers, anaesthetists, cardiologists and cardiothoracic surgeons while addressing the underlying MV pathology. 3D TOE imaging of MV provides en face 'surgical view' of the valve, which is a good match of what the surgeon expects to see in theatre. The

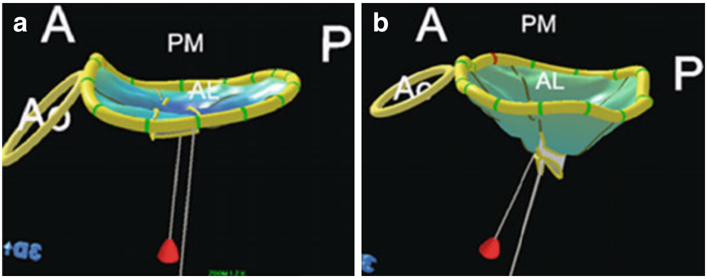

FIGURE 1.3 (**a**) Normal MV with a saddle shape of the annulus, with anterior and posterior points being higher than the posteromedial and anterolateral; (**b**) incompetent MV with leaflet coaptation defect as a result of ischaemic heart disease. Note the annular distortion, loss of saddle shape, significant tenting and ventricular displacement of mitral valve leaflets. *A* anterior, *P* posterior, *Ao* aorta, *AL* anterolateral, *PM* posteromedial

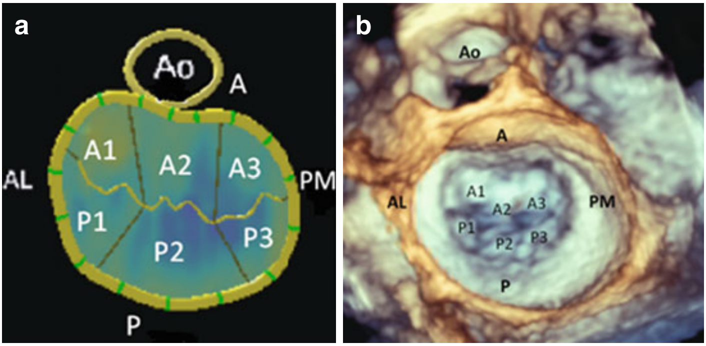

FIGURE 1.4 Carpentier's MV and scallop nomenclature in (**a**) reconstructed 3D MV model and (**b**) real-time 3D TOE 'surgical' en face view. *A* anterior, *P* posterior, *Ao* aorta, *AL* anterolateral, *PM* posteromedial, *A1*/*A2*/*A3* anterior mitral leaflet scallops, *P1*/*P2*/*P3* posterior mitral leaflet scallops

images can be rotated by 360° to visualize the valve from either left atrial or LV sides. 3D MV imaging allows comprehensive assessment of the anatomic lesion and its severity helps to estimate the potential success of valve repair or, alternatively, aid the surgeon to choose the valve replacement strategy.

Mitral Valve Regurgitation (MR) (Table 1.1)

Aethiology of mitral regurgitation is presented in Table 1.1.

Echocardiography is indispensable in planning surgical interventions for MR and describing the anatomy and mechanism of regurgitant lesions:

1. Leaflet morphology and mobility. Carpentier's classification of leaflet lesion type and motion disturbances distinguishes three major types of causes of MR.

TABLE 1.1 Aetiology of mitral regurgitation

Organic (primary) mitral regurgitation	Fibroelastic deficiency (FED) of the MV tissue (also known as degenerative or myxomatous mitral valve disease); Mitral valve prolapse; Infective endocarditis; Mechanical trauma (ruptured chordae, leaflet perforation); Rheumatic heart disease; Congenital structural abnormalities (prominent leaflet cleft, parachute mitral valve); Annular and leaflet calcification; Serotoninergic pharmacological substances (ergotamine, methysergide, pergolide, cabergoline, 3,4-methylenedioxymethamphetamine).
Functional (secondary) mitral regurgitation	Ischaemic heart disease; Systolic LV dysfunction, conduction disturbances (dyssynchronous contraction); Hypertrophic cardiomyopathy. Dilated cardiomyopathy; LV dilatation of other aethiology (e.g. due to long standing hypertensive heart disease).

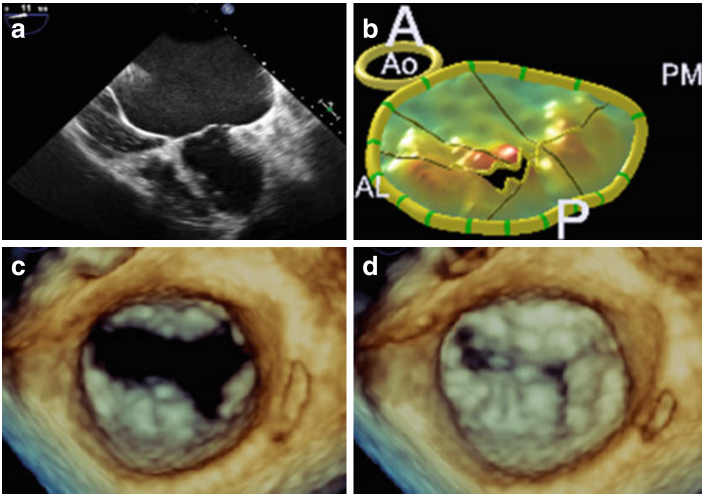

FIGURE 1.5 Mechanism of type I (Carpentier's) mitral valve insufficiency: (**a**) Significant mitral annular dilatation secondary to severe LA enlargement resulting in significant leaflet malcoaptation most appreciated on 3D TOE reconstructed mitral annular model (**b**). Note, a flattened annular shape and secondary prolapse of A2 segment. Pictures (**c**, **d**) show mitral valve cleft at 5 o'clock and another coaptation defect at the posteromedial commissure (10 o'clock) in diastole and systole respectively. *A* anterior, *Ao* aorta, *AL* anterolateral, *PM* posteromedial, *P* posterior

Type I: Normal leaflet motion. Mitral leaflet mobility is normal with no prolapse. MR is derived from a dilated mitral annulus, mitral cleft or leaflet perforation due to trauma or endocarditis (Fig. 1.5). This type also includes patients with dilated cardiomyopathy and functional MR in cases when the motion of the mitral valve leaflets is not restricted.

Type II: MV is structurally abnormal with one or more prolapsing parts. It is characterised by excessive leaflet motion often secondary to fibroelastic deficiency (FED), ruptured chordae or papillary muscles (Fig. 1.6).

Type III: The responsible mechanism of MR in this type is restricted leaflet motion. Based on the cardiac cycle in

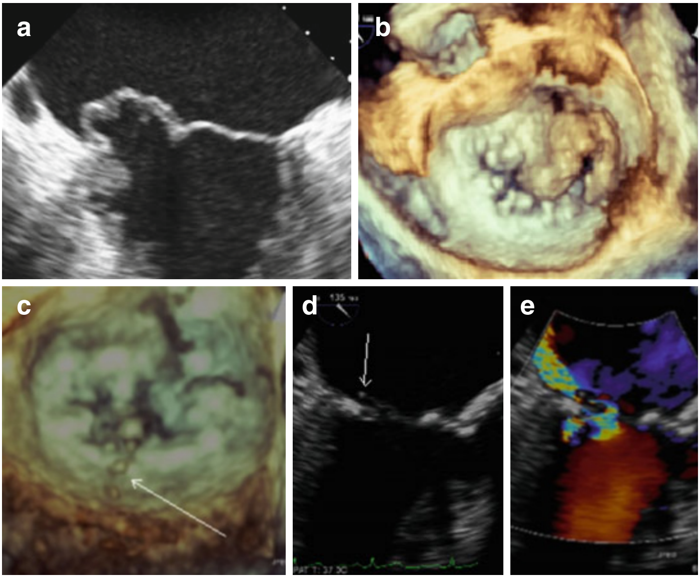

FIGURE 1.6 Type II (Carpentier's) mitral regurgitation. (**a**, **b**) show 2D and 3D TOE images of extensive myxomatous valve disease. There is thickening of the anterior MV leaflet, affecting all three leaflet segments, prolapse of A2 segment, A3/P3 segments and posteromedial commissure, which is best visualised in 3D en face view. (**c**–**e**): degenerative MV disease with a flail A2 segment secondary to a ruptured chord (*arrow*). Severe mitral regurgitation directed posteriorly

which leaflet restriction is observed, it is divided into two categories (Fig. 1.7).

Type **IIIa**: Systolic and diastolic restriction of leaflet motion (rheumatic heart disease);
Type **IIIb**: LV dilatation/ischaemia with systolic leaflet restriction (tenting of the leaflets).

2. Chordae level pathology. It includes chordae rupture, elongation (redundant chordae) and abnormal insertion, resulting in MV incompetence. Two papillary muscles provide chordae that attach to both mitral valve leaflets and

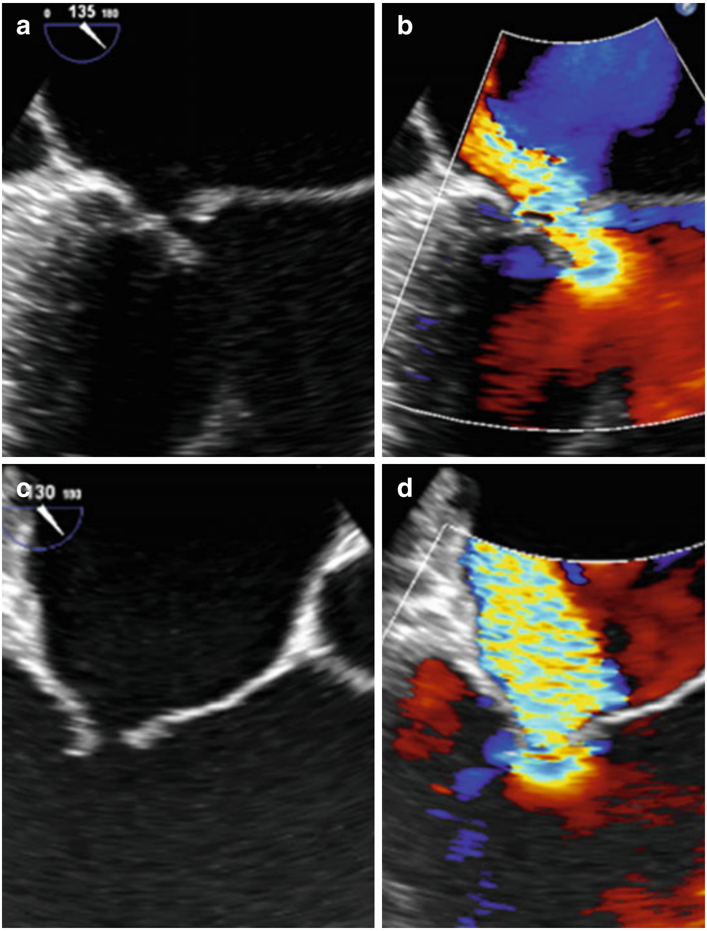

FIGURE 1.7 Type III (Carpentier's) MV regurgitation. (**a**): Type 3a. Rheumatic mitral valve with severely restricted posterior mitral valve leaflet (PML). The anterior leaflet is mobile and overrides the PML in systole, leading to a very eccentric and severe posteriorly directed MR jet (**b**). Both leaflets are thickened at the tips. (**c**) Type 3b. Dilated LV cavity due to ischaemic heart disease results in systolic and diastolic tenting and restriction of the MV leaflets, resulting in functional severe MR (**d**)

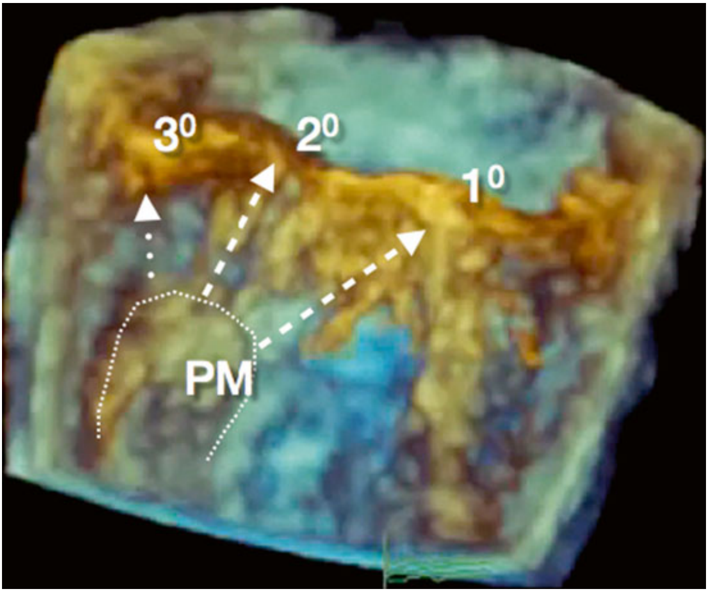

FIGURE 1.8 3D image of the mitral valve chordae: *1⁰* primary chordae attached to the tip of the mitral valve leaflet, *2⁰* secondary chordae to the ventricular surface of the valve, *3⁰* tertiary chordae, attached to the basal region of the leaflet. *PM* posteromedial papillary muscle

suspend the mitral valve, ensuring equal tension of the leaflets bodies during cardiac systole. Based on the level of leaflet attachment, the chordae are divided into the three following types:

- Primary chordae attach to the free edge of mitral valve leaflet;
- Secondary chordae attach to the ventricular surface of the valve;
- Tertiary chordae are attached to the basal region of the leaflets (Fig. 1.8).

3. Papillary muscle morphological and functional pathology. Two papillary muscles (anterolateral and posteromedial)

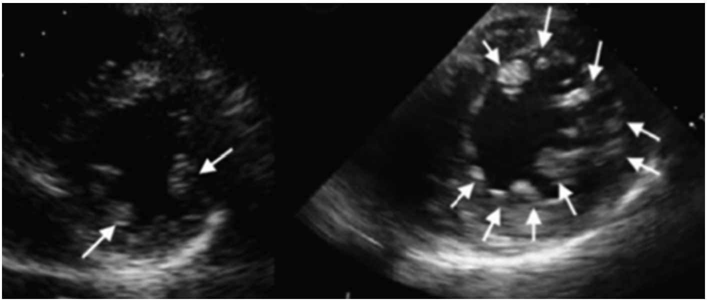

FIGURE 1.9 On the left – normal arrangement of papillary muscles (*two arrows*). On the right – abnormal arrangement of papillary muscles: several heads of papillary muscles, located anteriorly (*multiple arrows*)

serve as anatomical and functional links between the mitral valve, the subvalvular apparatus and the LV walls. They help to maintain optimal systolic tension of subvalvular structures, allowing adequate closure of the leaflets and preventing them from prolapsing above the annular plane. In structural abnormalities like papillary musclerupture, elongation, scarring, abnormal position or insertion, well balanced forces of the subvalvular apparatus are distorted, resulting in incompetent MV (Fig. 1.9). Functional papillary muscle pathology (dysfunction due to loss of contractility) interferes with timely closure of the valve and causes increased tenting of the valve, preventing adequate leaflet apposition and coaptation.

4. Myocardial pathology and dysfunction. The LV is the last, but not least, important element accounting for normal MV function and competence. LV dilatation causes displacement of papillary muscles, annular dilatation and increased systolic and diastolic tension of the valve, thus, impeding normal valve closure. Regional wall motion abnormalities, areas of thinning and ventricular aneurysms result in asymmetric tenting patterns of the MV apparatus and functional (ischemic) MR (Fig. 1.10).

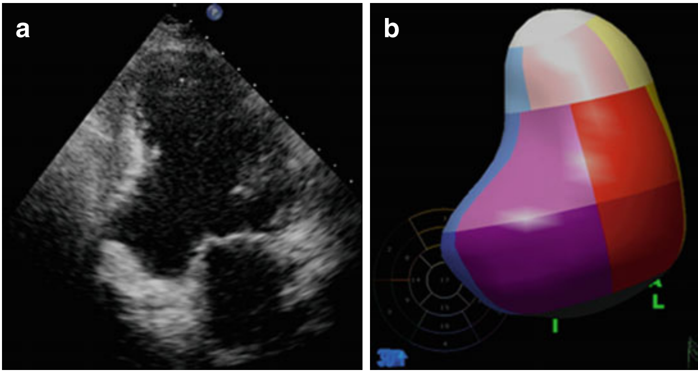

Figure 1.10 Inferior LV aneurysm with thrombus evident on 2D echocardiographic image (**a**) and 3D LV reconstruction (**b**)

Function

The severity of MR can be quantified by various echocardiographic techniques: colour flow jet area, vena contracta width, proximal isovelocity surface area (PISA) and detection of flow reversal in the pulmonary veins (Table 1.2). Assessment of regurgitant orifice area (ROA) by the PISA method is a recommended approach for MR estimation by TTE (Fig. 1.11). 3D echocardiography allows overcoming many limitations of conventional 2D echocardiographic assessment. 3D TOE provides direct planimetry of regurgitant orifices in an en face projection (Fig. 1.12). This also illustrates that often ROA is not circular, which is an erroneous assumption that the PISA method is based upon and there may be multiple regurgitant orifices and jets present (Fig. 1.13). 3D images allow detailed and comprehensive visual assessment of underlying structural and functional abnormalities of the mitral valve [5].

Preoperative 3D TOE allows the estimation of MV reparability and its use in the perioperative setting has contributed greatly to increase the success of MV repair. However, prebypass TOE is not a substitute for a comprehensive preoperative TTE/TOE assessment of MR severity or underlying lesion,

Table 1.2 Grading the severity of MR

	Mild	Moderate	Severe
Jet area/LA (%)	<20	20–40	>40
Vena contracta (mm)	<3	3–6	≥7
PISA radius (Nyquist 40 cm/s) (mm)	<4	4–9	>10
Regurgitant volume (ml)	<30	31–59	≥60
Regurgitant fraction (%)	<30	31–49	≥50
Regurgitant orifice area (cm^2)	<0.2	0.21–0.39	≥0.4

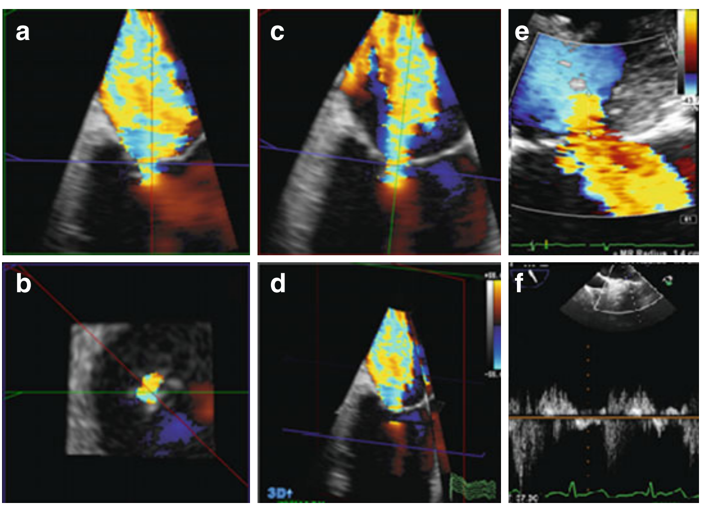

Figure 1.11 3D-guided 2D reconstruction of severe mitral regurgitation colour flow Doppler images (**a**–**d**). The cursors are placed at the tips of mitral valve leaflets and the neck (vena contracta) of the regurgitant MV jet. Off-line reconstruction allows appreciation of elliptical vena contracta and regurgitant orifice shape in functional mitral regurgitation. (**e**) Proximal isovelocity surface area (PISA) measurement on TOE color flow Doppler image. (**f**) Systolic flow reversal in the pulmonary veins is in keeping with severe mitral regurgitation

especially in functional MR, when loading conditions may significantly alter the degree of visible and measurable MR.

Whether a valve is suitable for repair depends on the pathology and the expertise of the surgeon (Table 1.3). Isolated

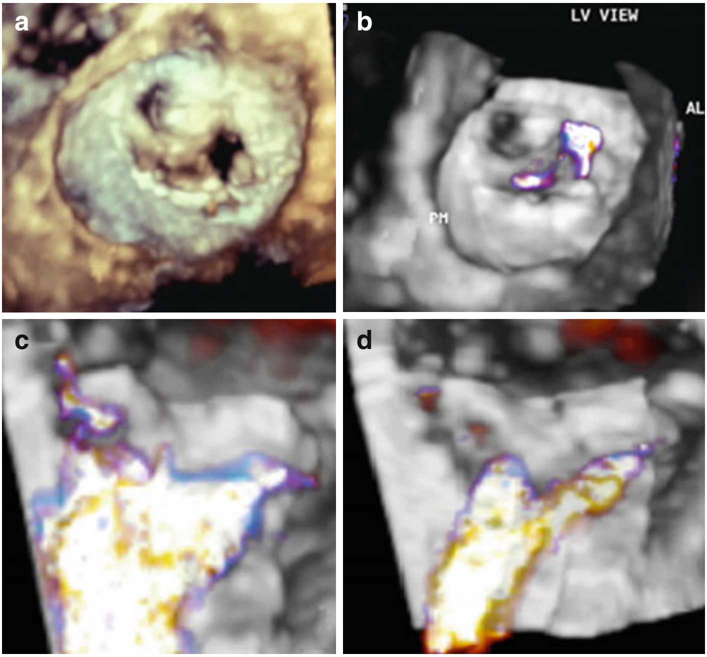

FIGURE 1.12 (**a, b**) 3D TOE imaging allows direct visualization of the regurgitant orifice (**a**) and regurgitant flow (**b**). Note the presence of two regurgitant orifices which would be otherwise difficult to appreciate on 2D imaging. (**c**, **d**) Degenerative mitral valve disease with diffuse severe MR arising along the leaflet coaptation line. 3D colour flow imaging allows better appreciation of dynamic functional MR nature: more MR is seen in early systole (**c**) compared to mid systole (**d**). (**e**, **f**) 3D MV imaging allows clarification of complex MR mechanism: a combination of factors is responsible for MR in the presented images (**e** LV side, **f** LA side). There is dominating degenerative MV disease with flail tip of A2 with ruptured small primary chord. There is also PMVL restriction secondary to left circumflex artery infarct and a cleft between P2/P3

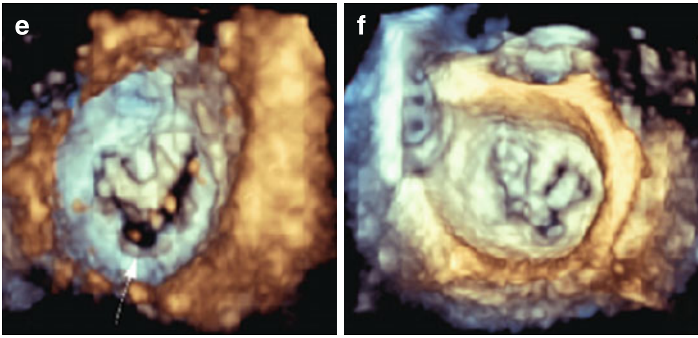

FIGURE 1.12 (continued)

repair of type 1 lesions or repairs of PML prolapse have excellent results [6]. The results of AML prolapse are less satisfactory; however, contemporary surgical techniques have shown to improve the results. The complexity of the repair increases with the increasing number of prolapsing scallops, commissural involvement and superimposed leaflet or annular calcification. Rheumatic MV disease is usually advanced and complex at the time of referral for surgery. A combination of thickened, calcified and deformed leaflets with commissural fusion, as well as subvalvular involvement, is generally unsuitable for MV repair. Chronic ischaemic MR is a result of LV remodelling: ischaemic injury and myocardial scarring leads to LV dilatation, increased papillary muscle separation and tenting of the valve leaflets, with restricted systolic motion and consequential MR. Generally, ischaemic MR is considered to be repairable. A careful assessment of the mechanism of mitral regurgitation will allow the surgeon to better select the type and extent of ischaemic MR repair. Different 3D TOE appearances of the mitral valve are depicted in Fig. 1.14.

The role of TOE is established in *guiding MV repair*. TOE is now essential for the surgeon to select the surgical repair strategy and technique. Approximately 1 in 10 MV repairs result in obstruction of the LV outflow tract (LVOT) due to systolic anterior motion (SAM) of the anterior mitral valve leaflet (AML) [7]. SAM can be predicted by a small LVOT diameter and increased posterior mitral valve leaflet (PML) length [8],

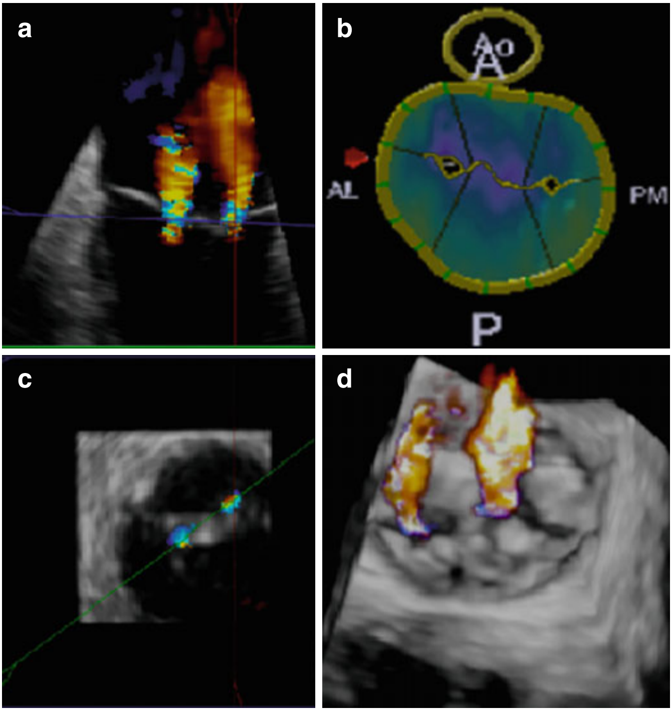

FIGURE 1.13 3D guided MV reconstruction and visualization of multiple MR jets: (**a**) 2D view of two MR jets; (**b**) 3D 'en face' MV reconstruction depicting two circular coaptation defects; (**c**) planar 'en face' visualization of regurgitant MV jets, allowing assessment of regurgitant orifice area; (**d**) 3D MV flow image allowing visualization of regurgitant jets and their origins. *A* anterior, *Ao* aorta, *AL* anterolateral, *PM* posteromedial, *P* posterior

coaptation point to interventricular septum distance less than 2.5 cm and the ratio of AML length to PML length of 1.3 cm or less [9]. 3D TOE provides dynamic measurements of the mitral annulus on a beating heart in systole and diastole while sizing the mitral annuloplasty ring. Larger ring sizes are suggested for cases of higher likelihood of postoperative SAM, while smaller rings are used in correcting ischaemic MR. Limited triangular or quadrangular resection is sufficient to resolve MR in isolated one scallop prolapse. However, in the pres-

TABLE 1.3 Criteria for determining MV suitability for repair

Location	Posterior location of MV lesion points towards a 'simple repair'. Anterior location of MV lesion indicates increasing complexity of surgical correction.
Number of segments involved	Lesions confined to a single MV segment (scallop) are the easiest to repair. Each added abnormal segment increases the technical difficulty of repair procedure.
Commissural lesion	Intact commissures reduce the complexity of repair, while their involvement points towards the necessity of complex surgical techniques.
Height of PML	Increased height of PML is a risk factor for postoperative SAM.

PML posterior mitral valve leaflet, *MV* mitral valve, *SAM* systolic anterior motion of the anterior mitral valve leaflet

ence of predictors of post-repair SAM, a sliding annuloplasty technique in addition to quadrangular resection of the PML to reduce its length is known to be advantageous. Determination of the morphology of complex prolapse (commissural, bileaflet) requires more complex surgical techniques, e. g. commissural plication, Alfieri technique (stitching together the tips of A2 and P2, and converting MV into a double orifice valve). Identification of chordal rupture or elongation directs to chordal transfer/shortening or replacement techniques.

Post-repair Assessment

Before assessing the results of a mitral valve repair, it is essential to bring up the systolic blood pressure (SBP) to just above 90–100 mmHg. Low SBP may seriously underestimate any residual MR.

Assessment of MV repair is comprised of the following key elements:

- **Residual MR**. Detection and quantification of residual MR is of paramount importance. If more than mild residual MR is present, the mechanism should be clarified (residual prolapse, excessive restriction, inadequate down-

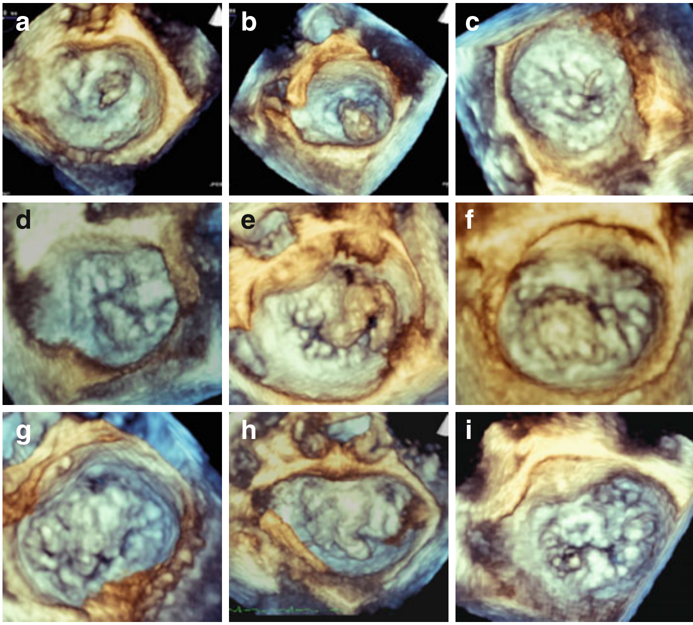

FIGURE 1.14 *Row 1*: Type 1 repairable MV lesions. (**a**, **b**) Large mobile echogenic mass with mobile serpingenous (?) elements attached to LA surface of P2 and posterior MV annulus visible on 3D MV views. (**c**) *Row 2*: Lesions, requiring more complex surgical approach to MV repair. (**d**) Degenerative mitral valve disease with P2 prolapse, extending to P1. (**e**) Extensive myxomatousmitral valve disease and dilated annulus. Thickening of the anterior leaflet affecting all 3 segments, but A2 and A3 are more markedly affected. Prolapse of A2 segment and flail A3/P3 segments and posteromedial commissure. Flail cords seen attached to A3 and P3. (**f**) Degenerative/ myxomatous mitral valve disease with extensive posterior leaflet prolapse mainly affecting the middle and lateral (P2 and P1) scallops. *Row 3*: Difficult to repair MV lesions: (**g**) degenerative mitral valve disease with bileaflet prolapse and loss of coaptation; (**h**) Elongated AML with a vegetation at the tip. There is prolapse of A2 and a flail A1 segment with a ruptured chord; (**i**) flail P1, prolapse of P3, degenerative MV disease

sizing of the annulus, paravalvular leak, leaflet perforation). Patients with greater than mild residual MR should be returned on CPB for further correction of MR as the risk of re-operation is high if more than mild MR is present after MV repair.

- Evaluation of **coaptation of the leaflets**. Each scallop and segment should be thoroughly evaluated for the adequacy of coaptationing mid systole. Leaflet coaptation height is measured by TOE and should be at least 5 mm in a satisfactory repair to ensure valve competence and long-term durability of repair [10].
- Assessment of **leaflet motion**. Residual or new restriction or prolapse may cause residual MR. It should be noted, that fixed and immobile PML, acting as a doorstop, and moving AML are normal echocardiographic findings following MV repair.
- **SAM** is featured in degenerative MV repairs with small LVOT diameter and lengthy PML. Following MV repair, the leaflet coaptation point is shifted towards the LVOT, resulting in systolic flow obstruction and posteriorly directed MR jet. The condition is worsened by volume depletion and hypercontractile LV. In mild forms of SAM, adequate LV filling and reduction of inotropic support may help. Significant SAM unamenable to conservative treatment requires return on CPB and surgical correction (sliding annuloplasty, larger annuloplasty ring or MV replacement).
- **Assessing the transvalvular gradient**. Mean transmitral gradient helps to exclude mitral stenosis following MV repair. It should be noted that the pressure half time method is unreliable postoperatively due to varying compliance of the LV and LA. A mean gradient of >5 mmHg is unacceptable and warrants correction or valve replacement, if further repair is not feasible.
- **Aortic regurgitation** must be looked for, keeping in mind the proximity of aortic and mitral valves. Surgical manoeuvers in the anterior MV annulus area and AML region may distort the aortic valve anatomy, resulting in new or worsened aortic regurgitation after MV surgery.

- **LV function**. As previously noted under LV function assessment, postoperative global and regional LV function must be assessed to identify potentially correctable myocardial ischaemia during the operation (e. g. surgical treatment in the anterolateral commissural region may result in accidental suturing or kinking of the left circumflex artery, which is found adjacently).

If mitral regurgitation is surgically managed by MV replacement, the motion of occluders must be visualised.

Mitral Valve Stenosis

Mitral valve stenosis (MS) was among the first valvular lesions assessed by echocardiography at the earliest stages of its application (Fig. 1.15). Since, in the majority of cases, it is predominantly rheumatic in origin, cases of MS are becoming less frequent. As in other valvular lesions, echocardiography is helpful in assessing the cause (rheumatic, calcific, congenital) and severity of this lesion (Table 1.4).

Planimetry is one of the most accurate measurements of mitral valve area (MVA) estimation. Real-time 3D echocardiography provides en face views of the mitral orifice and allows 3D-guided planimetry of the MVA: the coordinates of the cutting planes of interest can be adjusted and paralleled at the tips of the mitral valve leaflets, allowing precise measurement of the valve area contained by the open leaflet tips (Fig. 1.16).

Echocardiographic Findings

- Leaflet thickening;
- Diastolic doming of the anterior mitral valve leaflet;
- Reduced valve opening;
- Commissural fusion;
- Subvalvular involvement (chordal thickening and fusion);
- Secondary calcification;

Associated Findings

- Aortic valve involvement (in rheumatic disease);
- Left atrial enlargement;

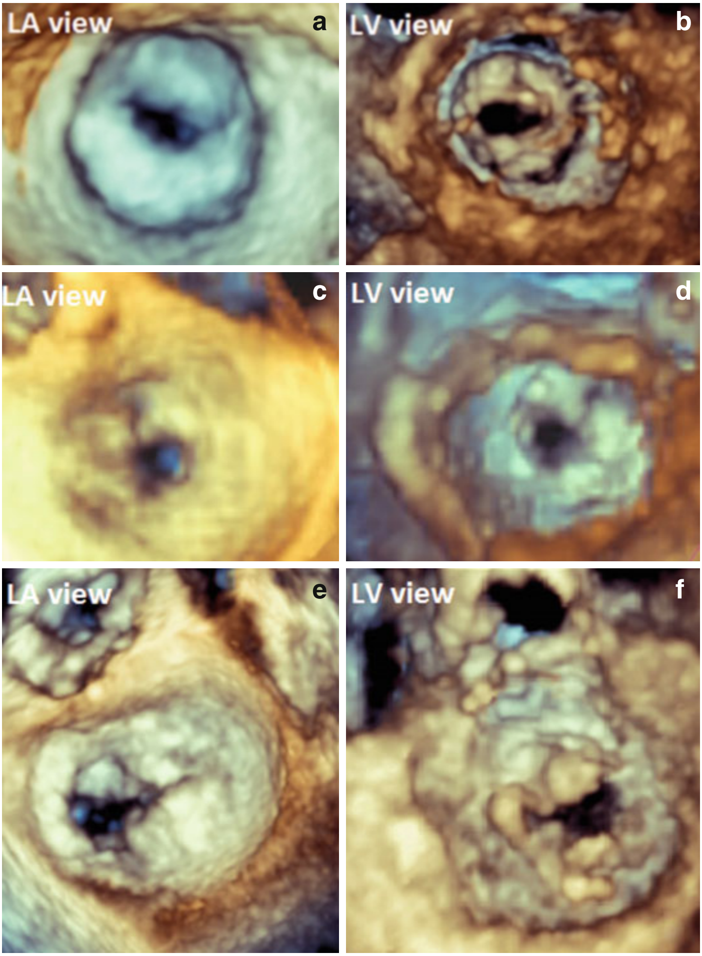

FIGURE 1.15 (**a**, **b**) Rheumatic mitral stenosis (MS) with visible, but identifiable, commissural fusion; favourable for balloon valvuloplasty. (**c**, **d**) Severe rheumatic mitral stenosis (MS) with symmetrically fused unidentifiable commissures; anatomy highly unfavourable for balloon valvuloplasty. (**e**, **f**) Calcific mitral stenosis. Posterior mitral annular calcification extends below the valve into the myocardium (**F** LV view). The calcium is more severe medially, leading to fusion of the PM commissure and immobile A3 and P3 scallops which appear fused. The A2 and P2 scallops are also affected with restricted mobility. Visible triangular valve opening only between A1 and P1 scallops

Table 1.4 Grading the severity of mitral stenosis

	Normal	Mild	Moderate	Severe
Pressure half time (ms)	40–70	71–139	140–219	>219
Mean pressure gradient (mmHg)		<5	5–10	>10
Mitral valve area (cm^2)	4.0–6.0	1.6–2.0	1.0–1.5	<1.0

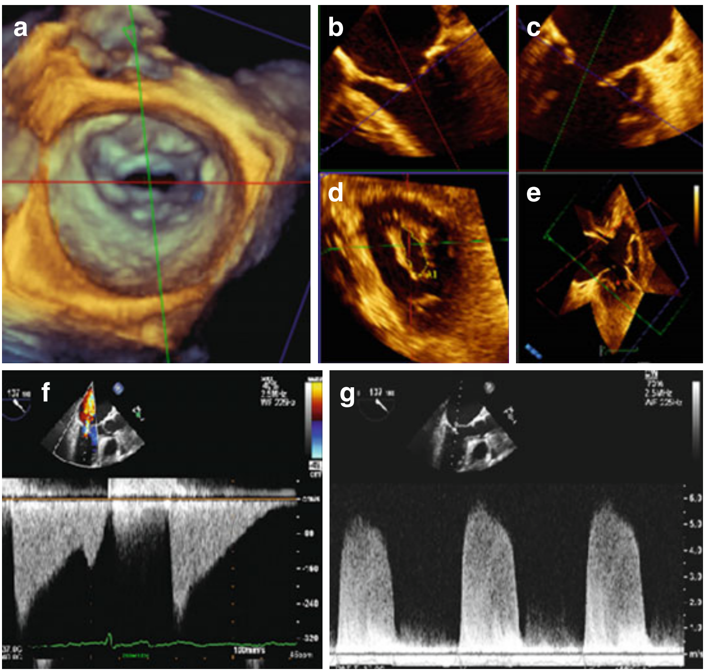

Figure 1.16 Assessment of severe mitral stenosis. (**a**) 3D imaging allows visualization of mitral valve opening and orifice area contained by mitral leaflets. Rheumatic mitral stenosis is illustrated. The opening of the mitral valve is seen from the LV side, with typical rheumatic valve and subvalvular apparatus appearance. (**b–e**) 3D-guided 2D planimetry of the valve area at the leaflet tips in mid diastole shows valve area of 1.2 cm^2. (**f**) Severe mitral stenosis with mean gradient of 13.3 mmHg and moderate MR (**g**)

- Spontaneous contrast in LA (look for thrombus in LAA appendage on TOE, Fig. 1.22);
- Tricuspid regurgitation;
- Pulmonary hypertension.

Echocardiography plays an important role in timing therapeutic intervention. Stress echocardiography in symptomatic patients with mild-to-moderate MS can explain the exertional symptoms by revealing increasing mean gradient and pulmonary hypertension with stress (rise of mean mitral valve gradient to 18 mmHg or above indicates a potential benefit from mitral valve intervention) [11]. For many years, surgical commissurotomy and open valvuloplasty were the only options for treating MS, apart from medical therapy. The introduction of percutaneous mitral balloon valvotomy (PMBV) in the 1980s has revolutionized the treatment of this disorder and is preferred over surgery, provided favourable MV morphology. However, surgical correction of MS is indicated in symptomatic moderate and severe MS if there are contraindications for PMBV: LA thrombus, moderate/severe MR, valve morphology that is unfavourable for PMBV (Figs. 1.15 and 1.17).

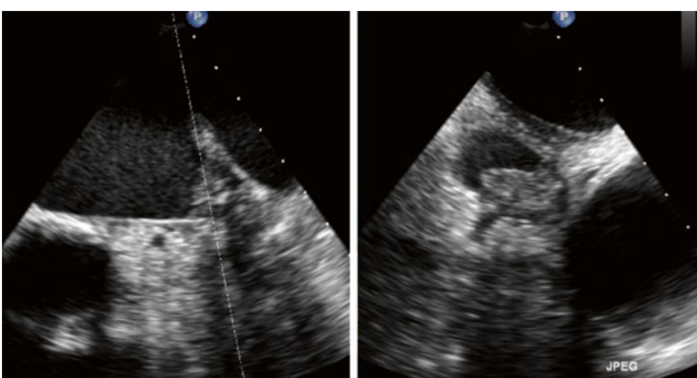

Figure 1.17 Thrombus in left atrial appendage, visualized from cross-sectional view. Note spontaneous contrast in LA cavity

Echocardiographic assessment of the extent of the likelihood of a successful result after PMBV includes the estimation of valvular and subvalvular deformity, evaluated by assigning a score of 0–4 (maximal score 16) for the following factors: leaflet mobility, leaflet thickening, leaflet calcification, subvalvular involvement. The higher the total score, the less likely PMBV will provide a good and durable result, therefore, surgery should be given priority in such cases. Current surgical techniques often allow the repair of even severely regurgitant and stenosed valves; if the stenosed MV cannot be repaired, MV replacement can be chosen (for postoperative assessment refer to assessment of MV repair).

Aortic Valve

The normal aortic valve is trileaflet. The non-coronary cusp is superior, next to the interatrial septum; the right coronary cusp lies inferiorly and the left coronary cusp is on the right and associated with the offset of the left main coronary artery seen at 3 o'clock (Fig. 1.18). The localized apical thickening of the free edge of each cusp (nodules of Arantius) is a normal finding. Some small fibrous strands may also be seen on TOE, their significance, however, is not always clear. These normal structures do not interfere with valve function and should not be confused with vegetations or fibroelastomas. 2D or 3D en face TOE views are particularly useful while assessing aortic valve area (AVA) by planimetry and colour flow Doppler with colour flow compare mode may help to identify the site of the leak or cusp coaptation defects. In long axis aortic valve views, one may identify diastolic prolapse or reduced cusp opening in stenotic disease.

Assessment of normal anatomy should always be followed by confirmation of normal physiology. Continuous flow (CW) Doppler in the aortic valve area and pulsed wave Doppler in the left ventricular outflow tract area should confirm normal transvalvular gradients with laminar flow. These parameters can be used for calculation of AVA by the volumetric method.

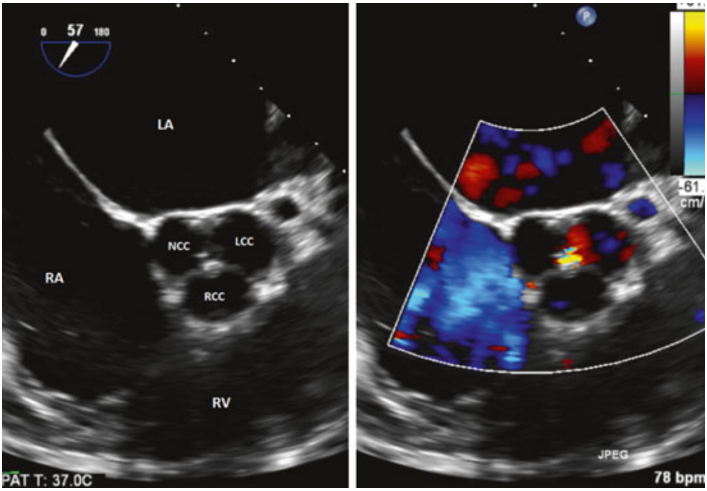

FIGURE 1.18 Mildly thickened aortic valve in diastole (*left*) with mild central mild aortic regurgitation, arising from the coaptation point of the cusps. *LA* left atrium, *RA* right atrium, *RV* right ventricle, *NCC* non-coronary cusp, *LCC* left coronary cusp, *RCC* right coronary cusp. Left coronary artery stem arises at 3 o'clock

Aortic Root

It is essential to look at the size and shape of the aortic root as the surgeons always take them into consideration. The aortic root is part of the ascending aorta defined by the LVOT and the aortic valve leaflets and the sinotubular junction (sinotubular ridge) [12] (Fig. 1.19).

LVOT is a region of the LV that is located between the anterior cusp of the MV insertion to the interventricular septum and the aortic annulus. Measurements of the LVOT are important in calculating the aortic valve area and selecting the diameter for the aortic valve prosthesis.

True (anatomical) *aortic annulus* is a complex three-dimensional crown-shaped structure formed by the anchoring of the aortic cusps to the walls of the aortic sinuses. It can be recognized by visual inspection by of the surgeon and the aid

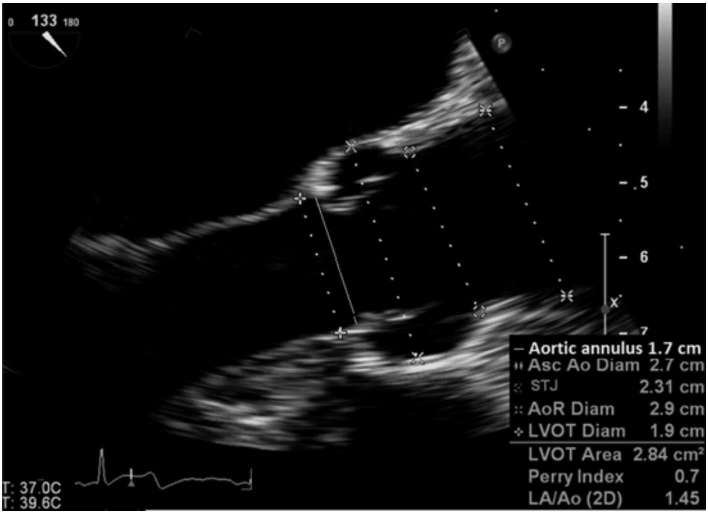

FIGURE 1.19 Aortic root measurements. From *left to right*: left ventricular outflow tract, aortic annulus, aortic sinuses, sinotubular junction and proximal ascending aorta

of 3D echocardiography. However, visualisation of this structure by either means is imperfect. Echocardiography often provides a simplified aortic annular measurement, taken at the base of aortic valve cusps. This virtual basal ring is often non-circular (may be oval or elliptical) and may be even more irregular due to superimposed calcification. It is important to keep in mind that a surgically implanted aortic valve prosthesis is sewn at the level of the anatomic aortic annulus (between the base of the leaflets and sinotubular junction) and even most advanced echocardiographic modalities (3D TOE) may underestimate the true aortic annular dimensions.

Aortic sinuses are anatomic recesses of proximal ascending aorta just above the aortic valve. There are generally three aortic sinuses, named after the valve cusps and coronary arteries that they are associated with: the left, the right and the non-coronary (or posterior).

Sinotubular junctionis is defined by the sinotubular ridge demarcating the junction of the aortic sinuses and proximal ascending aorta.

Ascending aorta continues its course as a tubular structure after the sinotubular junction and turns into the aortic arch at the upper sternal level. There is a 'blind spot' for echocardiographic imaging in the distal ascending aorta, just before the take-off of the innominate artery, attributable to interposition of the right bronchus and trachea. Aortic dimensions are strongly related to body surface area (BSA) and age, thus, these factors have to be taken into consideration while assessing aortic dilatation. TOE is superior to other imaging modalities in assessing aortic atheromas, as it provides information on size and mobility of the plaques in real time. Atheromas typically get worse proceeding distally, therefore, large mobile atheromas are unlikely to be found in the ascending aorta in the absence of distal aortic plaques.

TTE allows the assessment of aortic root and proximal ascending aorta; however, visualisation of the ascending aorta may be difficult, and measurements are known to significantly underestimate the true dimensions. In operating theatres, TOE is helpful in providing precise measurements of the aortic annulus, sinuses, sinotubular junction and the ascending and thoracic aorta. TOE overcomes the limitations of TTE in the assessment of the thoracic aorta and is valuable in assessing aortic dilatation, atherosclerosis, dissection and monitoring surgical treatment (Fig. 1.20) [13]. It is worthwhile noting that measures obtained by TOE are always greater than the analogous dimensions taken by TTE.

Aortic Regurgitation

Mechanism

Aortic regurgitation may be a result of functional or organic pathology or a combination of the both (Fig. 1.21).

Functional aortic regurgitation (often classified as Type 1) is a result of dilatation of the aortic root and consequential malcoaptation of the leaflets. The majority of these lesions are potentially repairable (if no significant calcification is present). If there is calcification present, the localization of it should be taken into consideration. Repair may be feasible if calcification is confined to the free margins without

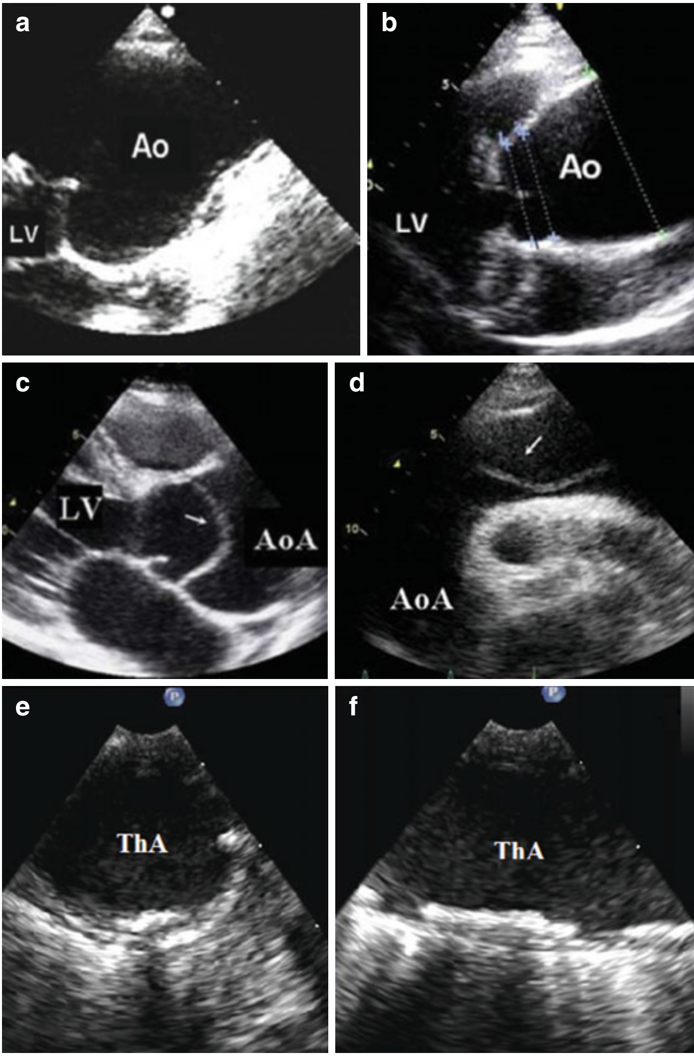

FIGURE 1.20 Aortic pathology. (**a**) Dilated aortic sinuses. (**b**) Dilated ascending aorta. (**c**) Dilated ascending aorta with visible dissection flap (*arrow*). (**d**) Aortic dissection intimal flap visible in the aortic arch. (**e**) Thoracic aorta with atherosclerotic plaques at 6 and 3 o'clock. (**f**) Longitudinal view of the thoracic aorta, allowing estimation of atheromatous plaque extent. *LV* left ventricle, *Ao* ascending aorta, *AoA* aortic aneurysm, *ThA* thoracic aorta

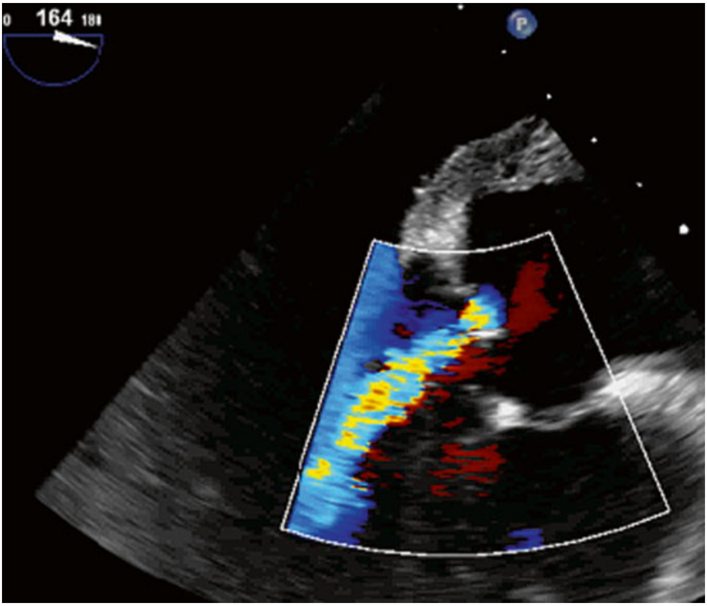

FIGURE 1.21 Aortic insufficiency jet visualised in the left ventricular outflow tract with colour flow Doppler

involvement of the body of the aortic valve cusps. Another important cause of functional aortic regurgitation is proximal aortic dissection. In such cases, aortic valve preservation is also often feasible, however, overall mortality rates are high.

Structural causes of aortic regurgitation are congenital aortic valve abnormalities (bicuspid, unicuspid, quadricuspid aortic valve), cusp prolapse/calcification due to degenerative valve disease, perforation/vegetations due to endocarditis and some other rare disorders. In cases of excess cusp motion with good cusp tissue quality (cusp prolapse, flail, and fenestration), valve repair may be considered and often may be successfully performed. However, if cusp tissue quality is poor (cusp retraction, extensive calcification, endocarditis) or there is mixed stenotic and regurgitant valve disease, the valve is generally considered unrepairable and replacement strategy should be chosen if surgical treatment is indicated [14].

Doppler echocardiography is the modality of choice in diagnosing and grading aortic regurgitation (AR) severity (Table 1.5), evaluating regurgitation mechanisms and determining the feasibility of valve repair. In many cases, the aetiology is identifiable on TTE/TOE (degenerative, rheumatic, congenital, endocarditis, aortic root dilatation, dissection).

Function

Determining LV function and dimensions in the presence of aortic valve incompetence is essential. Indexing of LV dimensions for BSA is recommended, especially in patients of small body habitus. Chronic severe regurgitation is highly unlikely in the absence of LV dilatation. The strongest echocardiographic predictors of operative mortality for aortic incompetence are LVEF <50 %, and LVESD >50 mm. Surgery should be considered in asymptomatic patients with resting EF >50 % with severe LV dilatation: LVEDD >70 mm or LVESD >50 mm or LVESD >25 mm/m^2 BSA [5].

The Role of Echocardiography in the Assessment of Aortic Regurgitant Lesions and Valve Repair

As with any valve repair, one of the primary roles of TOE in the perioperative setting is the assessment of the quality of valve repair. An optimal postoperative result is a pliable valve, opening well with no residual insufficiency [15]. Suggested assessment of aortic valve repair includes the assessment of:

- **Level of cusp coaptation**. Aortic cusps should coapt above the aortic annulus. If cusp coaptation occurs below the aortic annulus, there is significantly increased risk of recurrent AR [16].
- **Coaptation height**. Should be greater than 9 mm and reach the middle of the sinus of Valsalva.
- **Residual AR**. Underlying mechanism of AR, quality of valve tissue and patient factors (age, comorbidities and LV function) determine the decision of valve revision or replacement. The extent of residual AR on its own may not be a sufficient criterion for revision (minding difficulty

Table 1.5 Grading the severity of aortic regurgitation

	Mild	Moderate	Severe
Vena contracta[a] (mm)	<3	4–5	>6
Jet/LVOT diam. ratio[b] (%) (Fig. 1.22)	<25	26–64	≥65
Regurgitant volume[c] (ml)	<30	31–59	≥60
Regurgitant fraction[c] (%)	<30	31–49	≥50
Regurgitant orifice area[d] (cm^2)	<0.1	0.11–0.29	≥0.3
Pressure half time[e] (ms)	>500	499–250	<250
Diastolic flow reversal in desc. aorta[f]	–	±	++

[a]Vena contracta is the narrowest point of the regurgitant jet at the level of the aortic valve and provides a rough estimate of regurgitant orifice area

[b]Regurgitant jet/LV outflow tract (LVOT) ratio provides an estimation of regurgitant flow size in LVOT. However, this method is highly prone to underestimation of AR severity

[c]Regurgitant volume and fraction calculations can be obtained by measuring LV stroke volume at LVOT and MV levels and assessing the difference

[d]Quantitative Doppler echocardiography by proximal isovelocity surface area and ROA calculation is less sensitive to loading conditions, but is less well established than in MR and not routinely used

[e]Pressure half time represents the deceleration of the aortic regurgitant jet and equalization of LV and aortic pressures in diastole. LV systolic and diastolic dysfunction may lead to increased LV end-diastolic pressure, therefore, decreasing the PHT, but, despite this fact, PHT is a valid method for AR assessment

[f]Brief diastolic flow reversal in the thoracic aorta is a normal echocardiographic finding, ensuring continuous perfusion of head vessels and coronary bed. With greater AR grades duration and the velocity of diastolic flow reversal increase. Holodiastolic flow reversal is a specific for haemodynamically significant (moderate/severe) aortic regurgitation

of Doppler alignment and loading conditions while performing intraoperative TOE). The above mentioned level of coaptation compared to the annulus and coaptation height are more predictive parameters.

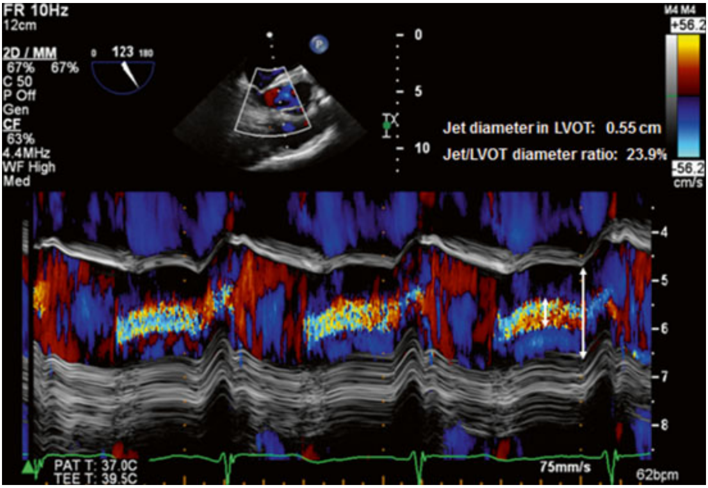

FIGURE 1.22 Color M-mode Doppler placed at the left ventricular outflow tract (LVOT) showing mild jet of aortic regurgitation (small white double-headed arrow) in the centre of LVOT (longer white double-headed arrow) during diastole

- **Peak AV gradient** estimation allows the exclusion of haemodynamically significant valvular stenosis.
- **LV function** assessment (minding proximity of coronary arteries in aortic valve surgery).

Aortic Valve Stenosis (AS) (Table 1.6)

AS is one of the most common valvular disorders and one of the a common indications for valve replacement surgery. Its frequency is increasing with the ageing population. By the time the patient arrives to the cardiac theatre, the diagnosis has usually been made (Table 1.7). So, the role of echocardiography is:

- Confirmation of the diagnosis by assessing peak/mean gradients through the valve and the level of obstruction. Subvalvular or supravalvular aortic stenosis can be a cause of high gradients across the aortic valve; however the valve appears structurally normal and the level of flow obstruction can be determined by echocardiography.

TABLE 1.6 Aetiology of aortic stenosis

Congenital aortic stenosis	Bicuspid aortic valve (Fig. 1.23);
	Unicuspid aortic valve;
Acquired aortic stenosis	Calcific disease of a native trileaflet aortic valve (age related);
	Calcific aortic valve disease in renal insufficiency;
	Rheumatic heart disease;
Rare causes	Metabolic disorders (Fabry's disease);
	Systemic lupus erythematosus;
	Paget's disease;
	Alkaptonuria.

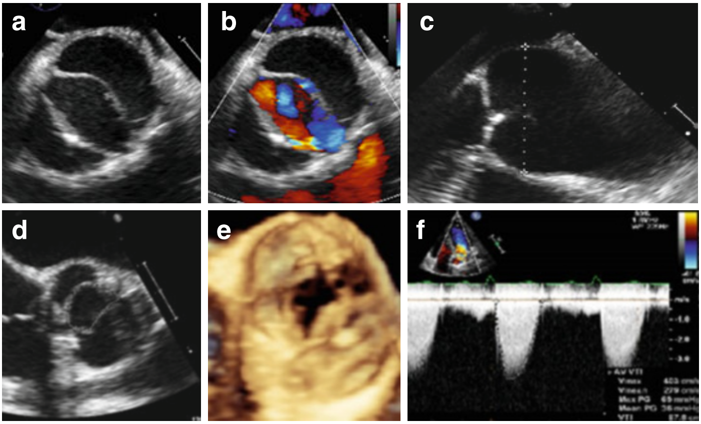

FIGURE 1.23 (**a**, **b**) Congenitally bicuspid aortic valve with no stenosis or regurgitation. (**c**) Dilated aortic root measuring 45 mm at sinus of Valsalva level. (**d**) Congenitally bicuspid aortic valve with moderate stenosis (aortic valve area by planimetry is 1.4 cm^2). (**e**) 3D image of the same valve. (**f**) Continuous flow Doppler through the same valve (as in **d** and **e**) showing peak/mean gradients of 67/37 mmHg. Assessment of aortic insufficiency by jet/LVOT ratio estimation

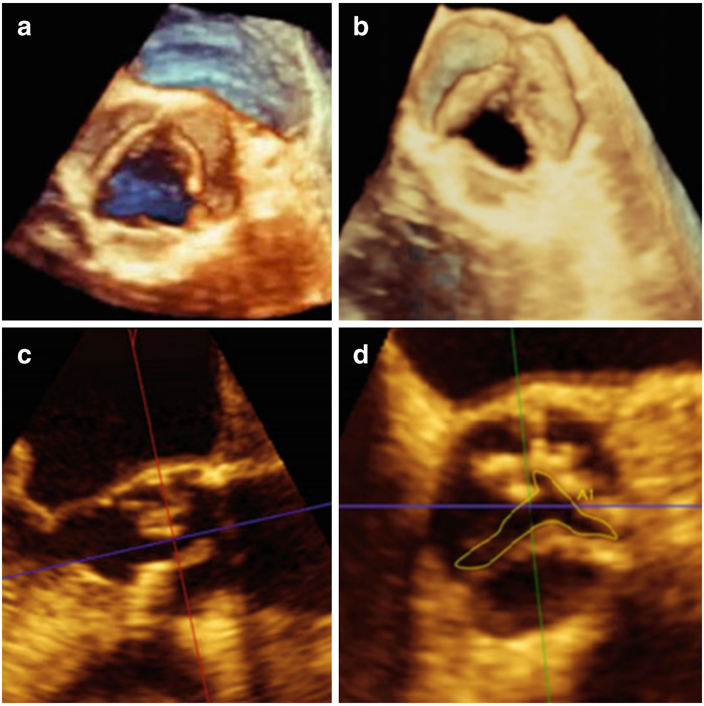

FIGURE 1.24 (**a**) Normal aortic valve with pliable cusps that open well. (**b**) moderate aortic valve stenosis with fused non-coronary and left-coronary cusps. Immobile right coronary and left coronary cusps with thickening and calcification of the edges of the cusps. (**c**, **d**) 3D-guided 2D planimetry of the aortic valve area in systole

In the perioperative setting, planimetry of AVA by 2D or 3D echocardiography is preferred for AVA assessment as the gradients under GA may be misleading and the severity of AS may not necessarily follow a high gradient (Fig. 1.24). There are situations whereby the patient may have a low gradient:

– 'Low gradient, low flow' AS is a recognized clinical and echocardiographic phenomenon: nearly 1/3 of all patients with significant LV impairment who undergo echocardiographic assessment for AS have calculated AVA in the severe range and other parameters suggesting mild or moderate disease. These patients may have true severe AS, with resultant LV, failure or impaired LV, unable to generate adequate force to fully open the valve [4]. The dobutamine challenge is useful in differentiating these cases preoperatively.

  – Paradoxical 'low gradient, low flow' AS with preserved LV systolic function. Current evidence suggests that a low gradient cannot exclude the presence of severe AS in the presence of small AVA and preserved LV EF, thus, a comprehensive diagnostic evaluation should be used to assess the stenosis severity, as aortic valve replacement might improve outcome of this patient subgroup [17].

- Assessment of valve morphology: tricuspid, bicuspid, size and symmetry of aortic sinuses. Calcific degenerative aortic stenosis is the commonest valve lesion in the ageing Western world population. On echocardiography, it is identifiable as trileaflet and calcified, with reduced cusp opening and mobility. The definitive surgical treatment option in severe symptomatic aortic stenosis is aortic valve replacement (AVR). AVR in patients with LV dysfunction carries high operative mortality, although those patients who do not undergo any intervention at all do even worse [18]. Transcatheter aortic valve implantation is an alternative option for this subgroup of patients if open heart surgery is deferred. Bicuspid aortic valve is another cause of isolated aortic stenosis in the younger age group. In such cases, repairability of the valve should be assessed as preservation of the native aortic valve is a possibility in the absence of significant valvular calcification. Rheumatic aortic stenosis can be recognized by commissural fusion and thickening. The mitral valve is also affected. Usually, valve replacement strategy is selected.
- Assessment of size and morphology of aortic sinuses, ascending and thoracic aorta. Echocardiographic information may provide information on the extent of aortic root dilatation, calcification and the presence of mobile atheromas, indicative

of increased risks of embolism or aortic cannulation. Extensive aortic calcification (porcelain aorta) is a considerable contraindication to AVR.

- Selection of the prosthetic valve type and size. Echocardiographically derived small aortic annular dimensions may lead towards the selection of a stentless bioprosthesis to prevent the patient-prosthesis mismatch [19].
- Defining the baseline LV function pre-bypass, evaluation of other valves and unexpected lesions;
- Post-operative assessment includes the assessment of transvalvular gradients, transvalvular or paravalvular regurgitation, LV function and integrity of the aortic wall (Table 1.7).

Tricuspid Valve

The tricuspid valve is often called the ‘forgotten’ or the ‘lost’ valve as it is relatively understudied in comparison to the other heart valves and the imaging of this valve is more difficult by TTE and TOE due to the inability to visualize its structures in one cross-sectional view (e. g. imaging of all three TV leaflets). However, recent advances in real-time 3D TOE has enabled en face visualisation of the tricuspid valve with the provision of the surgical view and reconstruction of the tricuspid anatomy (Fig. 1.26) [21]. Tricuspid regurgitation (TR) velocities provide a good estimation of non-invasive PA pressures in all cases of measurable TR (however, PA pressure estimation is unreliable in severe TR).

Echocardiography allows differentiation of functional (dilatation of RV and/or tricuspid annulus leading to malcoaptation of the leaflets) and organic TR causes (infective endocarditis, congenital anomalies, rheumatic disease, carcinoid syndrome, prolapse, trauma, iatrogenic complications). It allows the estimation of associated RV dilatation, functional impairment, volume overload and pulmonary hypertension. Tricuspid valve stenosis (TS) is rarely encountered in adults and nearly all the cases are attributable to rheumatic heart disease, affecting the mitral and/or aortic

TABLE 1.7 Grading the severity of aortic stenosis [20]

	Normal	Mild AoS	Moderate AoS	Severe AoS
Peak velocity (m/s)	–	<2.9	3.0–3.9	>4.0
Mean pressure gradient (mmHg)	–	<25	25–40	>40
Valve area (cm^2)[a]	>2.0	1.5–2.0	1.0–1.4	<1.0
LVOT/AoV velocity/VTI ratio	–	≥0.5	0.25–0.5	≤0.25

[a]Illustration of aortic valve area calculation is depicted in Fig. 1.25

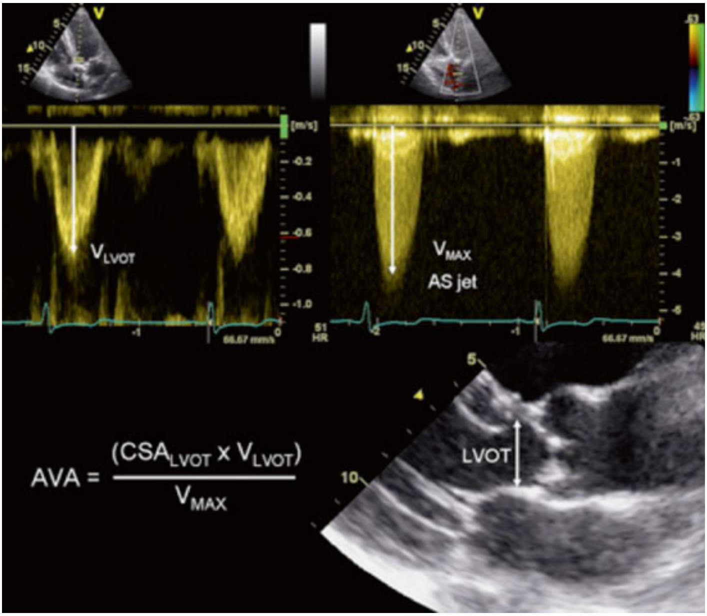

FIGURE 1.25 Assessment of the aortic valve area by continuity eq. is based on a concept that the flow in one area is equal to the flow in a second area if there are no shunts between them, thus, the flow at the left ventricular outflow tract (*LVOT*) is compared to the flow at the aortic valve. The aortic valve area (cm^2) is calculated by dividing the flow through the LVOT by the aortic flow measured on the spectral Doppler display using continuous-wave Doppler. *AVA* aortic valve area, *CSA* cross sectional area, V_{LVOT} velocity of the flow in the LVOT area, *Vmax* maximal velocity in the aortic valve area, *AS* aortic stenosis

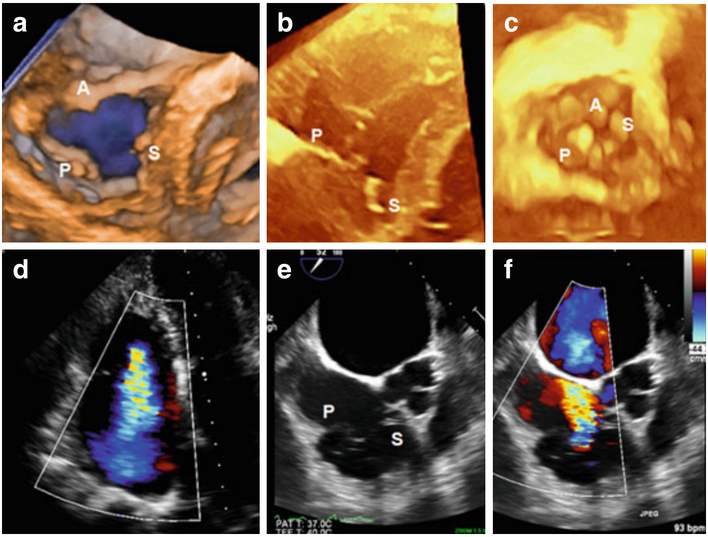

FIGURE 1.26 (**a**) 3D image of a tricuspid aortic valve 'en face' in diastole with visible three cusps: *A* anterior (*top*), *P* posterior (*left*) and *S* septal (*right*, attached to interventricular septum). (**b**) Conventional 2D image from transthoracic apical four chamber view allows visualization of posterior (*P*) and septal (*S*) tricuspid valve cusps. (**c**) 3D tricuspid valve image in systole. (**d**) Moderate to severe tricuspid valve regurgitation on TTE. (**e**) Imaging of tricuspid valve on TOE from short axis view. (**f**) Appearance of tricuspid regurgitation with colour Doppler

valves, concomitantly. In such cases, real-time 3D echocardiography provides a benefit of planimetric measurement of the tricuspid valve area.

The assessment of the tricuspid valve is also relevant in the context of other heart valve involvement, particularly in rheumatic valve disease where a degree of tricuspid regurgitation is usually present. Assessing TR is more of a challenge as quantification is not as straightforward as MR [5]. It is important to distinguish between its structural and functional causes and recognized the impact on RV function and volume overload.

Artificial Valves

Prior to evaluating the patient with an artificial valve, it is imperative to know the type and size of the valve, as different types of prosthetic valves have different flow characteristics.

Comprehensive echocardiographic assessment of the prosthetic valve function comprises the evaluation of valve leaflet/occluder morphology and mobility, peak and mean transvalvular gradients, effective orifice area (EOA) calculation, assessment of any transvalvular or paravalvular regurgitation and, finally, evaluation of LV dimensions and function and systolic pulmonary artery pressure [22]. These parameters obtained in operating theatre tend to change after the effects of GA wear off and the associated hyperdynamic state resolves. A baseline postoperative TTE assessment of prosthetic valve function is recommended to be performed before hospital discharge or 3–12 weeks after the operation.

Normal gradients through artificial valves are slightly higher than the gradients of normal native valves. Doppler echocardiographic parameters are presented for the normal prosthetic valves and suspected stenotic prosthetic valve dysfunction (Table 1.8). Abnormally high velocities and gradients through a prosthetic valve may be indicative of valve stenosis, patient-prosthesis mismatch (PPM), high flow states, regurgitation or localised high velocity central jet in bileaflet prostheses. TTE imaging is often difficult, especially in mechanical valves, due to reverberation and shadowing artefacts, therefore, TOE has marked superiority in prosthetic valve assessment. Valve type and size should be taken into consideration and effective orifice area (EOA) of the type and size of the implanted valve should be indexed to the patient's body surface area (BSA). In the early postoperative period, stentless bioprostheses, especially if implanted by subcoronary technique, may have higher gradients, which regress over a few weeks as the aortic wall oedema regresses and LVOT remodels (Fig. 1.27). If the EOA/BSA ratio is <0.85 cm^2/m^2 in the aortic position or <1.2 cm^2/m^2 in the mitral position, PPM is present and may totally or partially be

Table 1.8 Doppler echocardiographic assessment of prosthetic heart valves

	Normal		Possible stenosis		Definite stenosis	
	Aortic	Mitral	Aortic	Mitral	Aortic	Mitral
Structure and motion	normal	normal	often abnormal	often abnormal	abnormal	abnormal
Peak velocity (m/s)	<3	<1.9	3–4	1.9–2.5	>4	>2.5
Mean gradient (mmHg)	<20	≤5	20–35	6–10	>35	>10
Doppler velocity index	≥0.3	<2.2	0.25–0.29	2.2–2.5	<0.25	>2.5
Effective orifice area (cm^2)	>1.2	≥2	0.8–1.2	1–2	<0.8	<1
Jet contour	Triangular, early peaking	–	Triangular to intermediate	–	Rounded, symmetric	–
Acceleration time	<80	–	80–100	–	>100	–
Pressure half time	–	<130	–	130–200	–	>200

Adapted from Pibarot and Dumesnil [22]

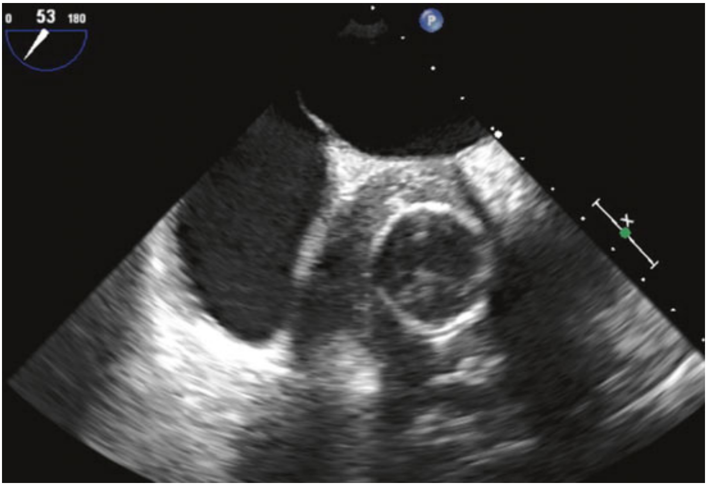

FIGURE 1.27 Bioprosthetic aortic valve. There is heterogeneous opacification surrounding the aortic root, suggesting haematoma related to surgery

responsible for high transvalvular gradients. If PPM is excluded or not severe enough to account for transvalvular gradient leaflet/occluder mobility, calcification, additional structures (thrombus, pannus and presence of vegetations) and pathological regurgitation have to be looked for. In the absence of any abnormal findings or hyperdynamic state, the possibility of a technical error should be considered, especially in measuring LVOT dimension.

Normal bioprosthetic valves are usually trileaflet (irrespective of implantation position) and, similarly to native valves, should have no more than trace regurgitation detectable on echocardiographic assessment through the central leaflet coaptation point. In the meantime, mechanical prostheses have a degree (not more than mild) of 'built-in' regurgitation known as 'washing jets' (minimal back leakage necessary to close the valve occluders), which is detectable and characteristic for each valve model, depending on architecture, number of leaflets and orifices. Normal closing jets

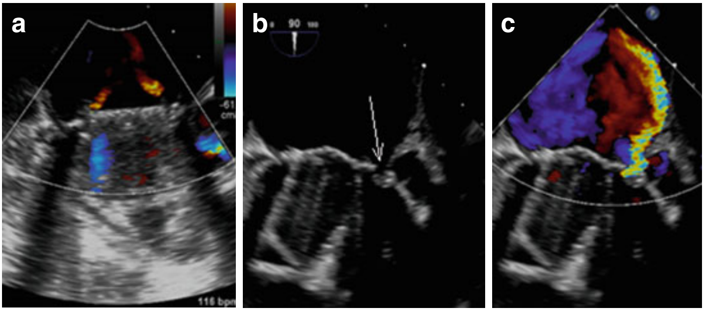

FIGURE 1.28 Mechanical bileaflet mitral valve. (**a**) Normal washing jets. (**b**) Paravalvular defect visualized on 2D TOE images (*arrow*). (**c**) Paraprosthetic regurgitant jet seen on colour Doppler image

are brief, narrow and symmetric (Fig. 1.28). Difficult visualisation of allogeneic structures in the heart and the possibility of complex regurgitant mechanisms (paraprosthetic leaks, eccentricjets) make detection and quantification of prosthetic valve regurgitation challenging. In the presence of significant regurgitation, it is important to localize the location, determine the mechanism and quantify its severity (Figs. 1.29, 1.30, and 1.31). It is important to note that methods of regurgitant native valve lesion quantification are applicable in such cases, however, less reliable, especially when multiple jets are present.

Myectomy

In cases where surgical myectomy is indicated to treat dynamic LVOT obstruction due to asymmetric septal hypertrophy, intraoperative TOE should be interpreted with caution due to differences between ambulatory haemodynamic conditions and the state under general anaesthesia. The LVOT gradient may be less than the gradient measured at the echo department or in the cath lab. In some cases, preoperative TOE may reveal other causes of elevated LVOT gradient (subaortic membrane, SAM due to organic MV disease), especially in patients who are referred for surgery based on

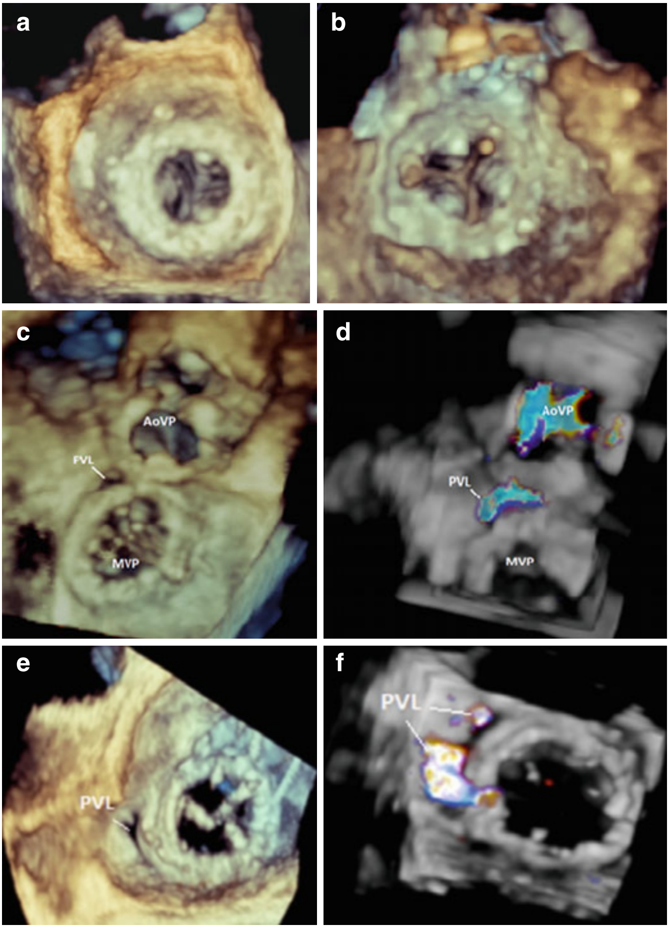

FIGURE 1.29 (**a**) Bioprosthetic valve in the mitral position with normal appearance from the LA side (**a**) and LV side (**b**). (**c**) Double prosthetic valve – mechanical in mitral valve position (*MVP*) and bioprosthetic in AoV position (*AoVP*). Anterior paravalvular MVP leak (*PVL*) between the aorta and the anterior part of the mitral valve. (**d**) Paraprosthetic regurgitation occurring in systole, concomitantly with normal transaortic flow. (**e**) The tissue bioprosthesis in the mitral position with visible paraprosthetic defect. (**f**) There is paravalvular regurgitation arising from two holes around the anterolateral portion of the valve (9 and 11 o'clock), adjacent to the LAA. The second hole is small and invisible on plain 3D en face image. No transvalvular MR

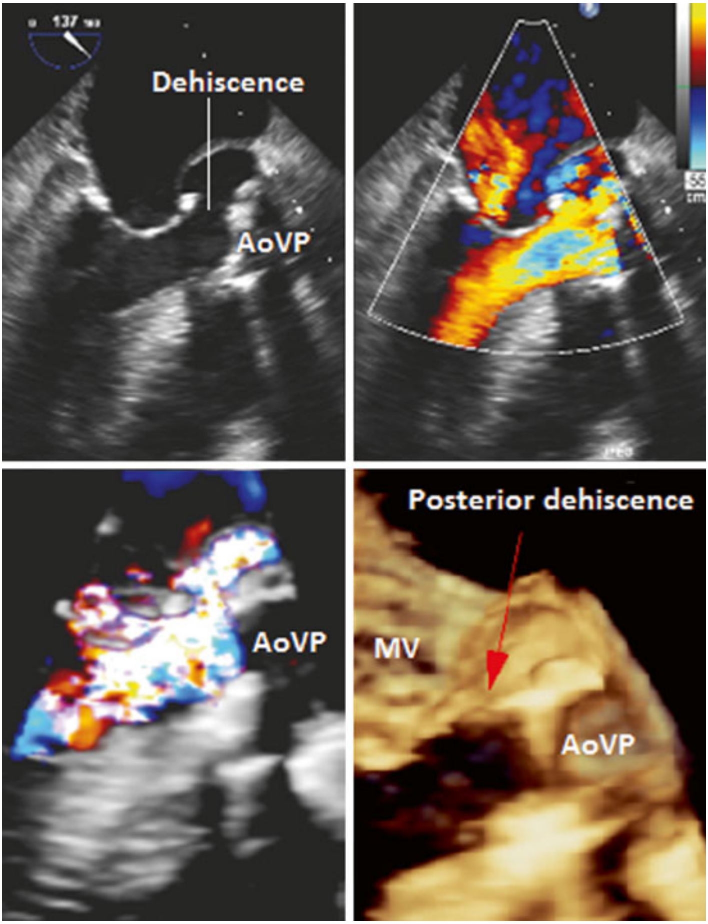

FIGURE 1.30 Severe paravalvular aortic regurgitation with a large posterior region of AVR dehiscence. *AoVP* aortic valve prosthesis, *MV* mitral valve

sole TTE assessment. Thus, care should be taken to confirm the diagnosis preoperatively and determine the surgical goal (Fig. 1.32). The role of intraoperative TOE is to define the thickness of the interventricular septum, determine the location of myectomy by assessing the length and amount of contact of AML with the interventricular septum during

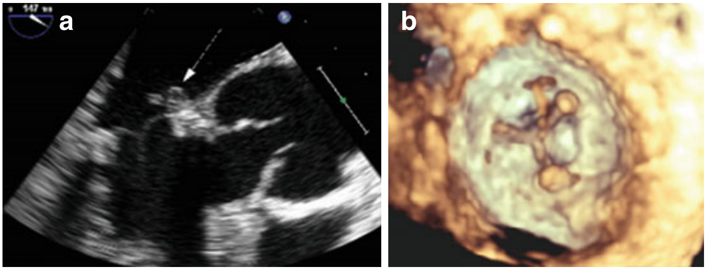

FIGURE 1.31 Prosthetic valve endocarditis. Biological trileaflet mitral valve bioprosthesis. (a) Hypodense mass is seen adherent to the anterior sewing ring (*arrow*) with mobile strands. (**b**) On 3D images, at least two long linear mobile structures (vegetations) are seen attached to the bioprosthesis from the left ventricular side

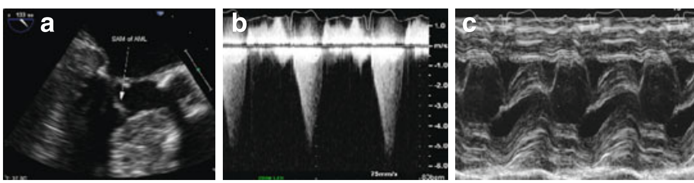

FIGURE 1.32 (**a**) Systolic anterior motion (SAM) on 2D TOE image; (**b**) dagger-shaped continuous wave Doppler tracing in the left ventricular outflow tract area: peak/mean gradients 113/51 mmHg; (**c**) transthoracic M-mode tracing through the LV cavity demonstrating SAM

SAM to assist the surgeon in planning the location and extent of myectomy through aortotomy. After myectomy, persisting SAM, MR and iatrogenic VSD should be looked for and residual gradient in the LVOT should be assessed [23].

Postoperative Complications

Intraoperative TOE provides allows quick evaluation of cardiac haemodynamics and rapid diagnosis in potentially life-threatening complications in the cardiothoracic theatre setting where prompt decision making is of paramount importance. In cases of difficult weaning of patients off-bypass, echocardiography can promptly detect the following postoperative complications:

- Left or right ventricular failure: RV/LV dilatation with decreased systolic function; new regional WMA are findings alerting of myocardial ischemia and its location needs to be identified;
- Mechanical complications (iatrogenic aortic dissection following cross-clamping); valve leaflet perforation, resulting in new or worsened regurgitant lesions (Fig. 1.33);
- Valve/LVOT obstruction: transvalvular/LVOT gradients; leaflet/occluder motion helps to detect these abnormalities (Fig. 1.34). Raising systemic blood pressure may help to unmask latent valve incompetence or worsening LVOT obstruction.

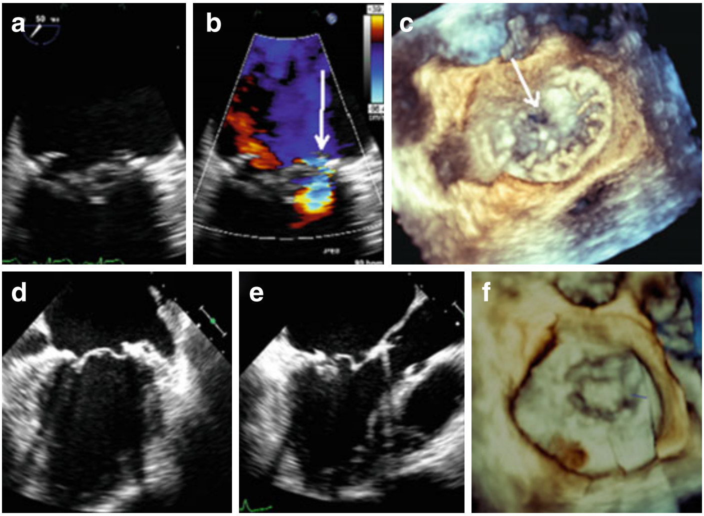

FIGURE 1.33 (**a**) 2D TOE view post mitral valve repair. (**b**) Colour flow Doppler showing a spot of regurgitation through the defect in the anterior mitral valve leafet body (*arrow*). (**c**) 3D en face view of repaired mitral valve with annuloplasty ring MV and neochordae to the posterior mitral valve leaflet and visible site of anterior mitral valve leaflet perforation (*arrow*). (**d**, **e**) Residual A2 prolapse with failure of coaptation after MV repair. Annuloplasty band in situ. (**f**) 3D view of prolapsing A2 of the valve depicted in (**d**) and (**e**)

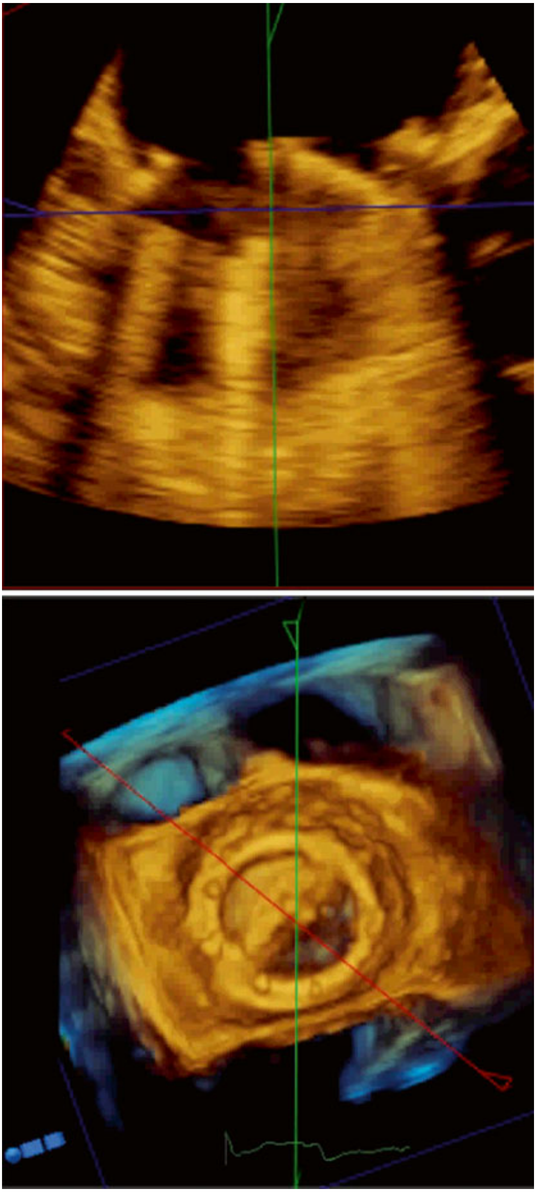

FIGURE 1.34 Mechanical bileaflet valve in the mitral position. The opening of the posterior occluder is restricted, as seen on 2D and 3D images

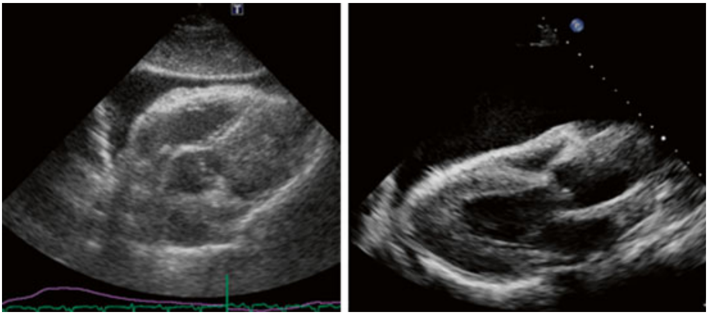

FIGURE 1.35 Image on the *left*: small- to medium-sized pericardial effusion. Image on the *right*: large pericardial effusion with evidence of right ventricular diastolic compression indicative of cardiac tamponade

- Persistent or new valvular/paravalvular regurgitation;
- New or residual intracardiac shunts (ASD in MV approach through RA, VSD in surgical myectomy of interventricular septum);
- Pericardial effusion and cardiac tamponade manifesting as cardiac arrest or haemodynamic deterioration when the patient is fully off bypass and the surgical wound is closed (usually in the intensive care unit) (Fig. 1.35).

The pitfall of 2D echocardiography is the inability to provide real three-dimensional anatomy, which often yields the diagnosis, especially when assessing valvular structures. Single views often miss important structural or flow patterns. Multiple imaging planes and 3D TOE imaging should be used in order to overcome this limitation. Side-by-side comparison to pre-bypass images is also useful and, therefore, complete and comprehensive TOE assessment should be performed before and after CPB.

The role of intraoperative TOE is mostly appreciated when quick and definite information on cardiac function and haemodynamics needs to be obtained in real time. Perioperative echocardiography is a highly reliable imaging tool when being handled and interpreted with sufficient expertise when critical decisions have to be made. Current trends towards the introduction of accreditation in transthoracic, transoesophageal and critical care echocardiography highlights the importance of achieving and maintaining high standards while operating this imaging technique.

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Chapter 2
Basic Setup in Cardiac Surgery

Prakash P. Punjabi and K.M. John Chan

Introduction

Conventional cardiac surgery is usually carried out through a median sternotomy. This is usually a straightforward procedure, but certain principles are important to ensure safe entry to the heart. Particular care is needed in re-operations. Most cardiac operations are performed on cardiopulmonary bypass. Safe and effective methods of cannulation of the various vessels and venting the heart are important. A secure technique of closing the chest is necessary to avoid the risk of subsequent sternal wound dehiscence or infection.

Sternotomy

A midline incision is made from the suprasternal notch to the xiphisternum. The midline of the sternum is easily determined by locating the suprasternal notch and the centre of the xiphisternum between the rectus sheath on either side and joining the two together. Locating the intercostal spaces on either side of the sternum and the edges of the muscle fibres along the sternum further aids this. It is common for the sternum to be marked with diathermy in the midline prior to sternotomy. A superificial mark on the fibrous layer over the sternum is sufficient. It is unnecessary to make a deep

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mark on the sternum as this may devascularise it, especially if the sternotomy does not go through this mark.

The xiphisternum is cut with scissors and the pericardium freed from under the sternum with the right index finger. This is an important manoeuvre to ensure that the pericardium is below the plane of the sternotomy. The sternum is cut with a saw. If resistance is encountered, the saw should simply be moved backwards to release any tissue caught in it and advanced again.

Redo Sternotomy

In redo sternotomy, the sternal wires are untwisted and removed or they can be left in place after dividing and separating them to prevent the oscillating saw from cutting too deep. Three thick strong sutures are placed through the costal cartilage on either side of the sternum about 2–3 cm from the midline. The assistant lifts these up during the redo sternotomy to separate the sternum from the underlying tissues. The dissection is started at the bottom under direct vision by lifting up the xiphisternum. Almost the lower third of the sternum can be freed of adhesions. The anaesthetist is then asked to hyperinflate the lungs to a maximum pressure of 30 cm of H_2O. This manoeuver widens the potential retrosternal space between the sternum and the heart to minimise injury [1]. Hyperinflation, by generating positive pressure inspiration, decreases caval flow and right ventricular (RV) dimensions. The sternum is divided with the oscillating saw. As the sternum is split, the sternal edges are separated and kept apart with the help of a flat instrument (e.g. flat end of sternal saw key) and underlying tissue is cut with curved Mayo scissors. The lungs are kept hyperinflated without deflation during sternotomy, although this may be repeated with intermittent normal ventilation to prevent hypoxia until complete sternal division. Once fully divided, standard ventilation is recommenced. A backhand or cat's paw retractor is then used to lift the posterior table of the sternum for further dissection on both sides. This is continued until the sternum is completely separate and can be safely retracted.

Dividing the Pericardium

Following sternotomy, the fat over the lower part of the pericardium can simply be pushed apart with a swab along its natural plane. This minimises cutting through fat with diathermy and bleeding. The pericardium is opened in the midline up to the pericardial reflection, superiorly. The pericardium over the aorta at the pericardial reflection should be left so as not to weaken the aorta.

Towels are placed on the sternal edge. The pericardium is lifted up using Roberts and the sternal retractor is placed on the pericardium to support it. The anaesthetist should be cautioned during this manoeuvre as the blood pressure may drop transiently due to kinking of the SVC and IVC. Should the patient be unstable, then pericardial stay sutures can be taken without lifting the heart. In general, patients with poor left ventricular function usually do not drop their blood pressure significantly on lifting the pericardium as the heart is usually well filled in these patients. Patients with good left ventricular function usually drop their blood pressure during this manoeuvre but it usually recovers quickly.

Placing a Sling Around the Aorta

It may sometimes be desirable to place a sling around the aorta. The aorta has to be mobilised for this and this ensures that when the cross-clamp is applied, it is placed across the full diameter of the aorta. The pulmonary artery is separated from the aorta, usually at the site where the curvature of the aorta is most anterior, by a combination of sharp and blunt dissection. Dissection should be parallel to the aorta and pulmonary artery to avoid damage to either of the great vessels. The pulmonary artery can sometimes be very thin-walled and care must be taken to avoid damage to it. The dissection in such cases should be more towards the aorta. Once a sufficient plane has been developed, the thumb and index finger is placed around the aorta in the transverse sinus to ensure that the back wall of the aorta is also free of tissue. A Semb clamp is then advanced around the back of the aorta while in contact with the index finger. It is withdrawn back after grabbing an umbilical tape.

Injury to the Pulmonary Artery

If the pulmonary artery is injured, it may be preferable to go on cardiopulmonary bypass to repair it. This allows blood conservation and visualisation as the right atrium and pulmonary artery will empty of blood.

Thin or Fractured Sternum

If the sternum is osteoporotic or fractured as a result of an off-centre sternotomy, it can be supported by cutting either a 32 Fr chest drain or a venous drainage line in half longitudinally and placing this on the sternum on top of which the retractor blade is placed. This may limit further damage to the sternum.

Cannulation

A diamond-shaped purse string is placed on the aorta just below the pericardial reflection (Fig. 2.1). Two purse strings are used, starting at opposite ends to each other. The inner purse string is usually placed starting at the assistant's side. The purse string should run through the aortic media. Should the stitch go right through into the aortic lumen, it should be removed and a new bite taken. A haematoma will inevitably form if this happens. The adventitia should be cut to relieve it.

The aorta is incised with a size 11 blade and advanced about 2 mm, with the left index finger covering the incision. The incision should be just slightly smaller than the diameter of the aortic cannula to allow it to pass easily into the aortic lumen and without any leaks after cannulation. It is important

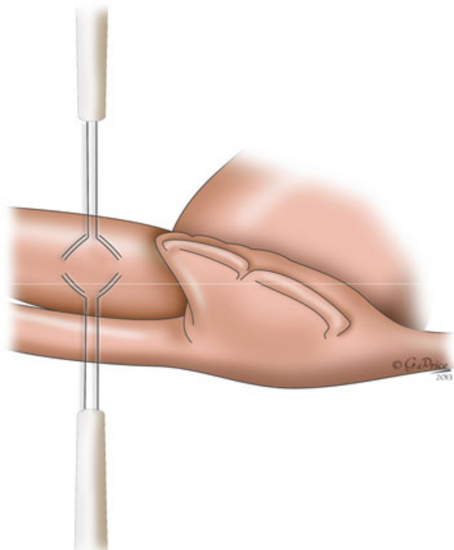

FIGURE 2.1 Placement of purse string sutures on the ascending aorta in preparation for cannulation (Printed with permission © Gemma Price)

to ensure that the systolic blood pressure is less than 120 mmHg when cannulating the aorta to avoid aortic dissection.

Single Two-stage Cannula

A "D"-shaped purse string is placed in the right atrium following the curve of the needle. Small bites should be taken around the right atrium. The right atrium is held medially with a Duval by an assisstant and laterally by the surgeon with a pair of forceps. A 2-cm vertical incision is made in the right atrium with an 11 blade. This incision is then dilated with scissor or a Roberts until it is about the size of the venous cannula. The right atrium is then cannulated.

Double Venous Cannulation

To cannulate the SVC and IVC separately, the SVC can be cannulated through an incision in the right atrium, with the cannula directed superiorly towards the SVC. It can also be cannulated directly through an incision on it. The IVC is cannulated through an incision placed about 2 cm above the junction of the IVC with the right atrium.

Both the SVC and IVC should be isolated and have umbilical tapes placed around them. To isolate the SVC, the assistant applies gentle traction on the umbilical tape around the aorta, retracting it towards the left and exposing the pericardium covering the SVC on its left. The pericardium, at this point, is just above the right pulmonary artery. It is lifted up and cut to create a plane around the SVC. The pericardium on the right side of the SVC is also lifted up and cut. The thumb and index finger are then placed around the SVC to ensure that an adequate plane has been created. An O'Shaunessey clamp is then placed round the back of the SVC from right to left. An umbilical tape is placed on it by an assistant and the clamp withdrawn. To isolate the IVC, the heart is mobilised gently by blunt dissection, near its junction with the IVC. The middle finger and thumb of the right hand can easily then go around the IVC, meeting each other, followed by passing a Semb clamp through this plane and grabbing an umbilical tape with it on withdrawal. It is often easier to perform this on cardiopulmonary bypass.

Femoral Artery and Femoral Venous Cannulation

An incision is made above the femoral artery in the groin crease in the femoral or midinguinal point (midway between the pubic symphysis and the anterior superior iliac spine). It is easier to have these landmarks marked with a pen before drapping the patient. After the femoral artery is exposed, tapes are placed above and below the intended site of incision for cannulation. This site of cannulation should be above the origin of the profunda femoris. Vascular clamps may be applied above and below the intended cannulation site. An 8–10 mm arteriotomy is performed. The femoral cannula is then inserted. The tapes are then snugged down onto the cannula. The femoral vein can be cannulated in a similar way.

Decompressing the Heart

The heart can be vented through the right superior pulmonary vein, the pulmonary artery or the left ventricle.

Right Superior Pulmonary Vein Vent

A purse string is placed around the right superior pulmonary vein. It is important to place full thickness bites through the right superior pulmonary vein and not just through the pericardium. An incision is then made with an 11 blade. This incision is then dilated with a Roberts. A thin malleable vent is then inserted, directing it towards the left ventricle.

Pulmonary Artery Vent

An horizontal incision is made on the pulmonary artery just distal to the pulmonary valve. A bullet pump suction is inserted into it.

Left Ventricle Apex Vent

The heart is lifted up and a stab incision is made at the apex of the left ventricle with an 11 blade. A bullet pump suction is placed into this. This incision is closed at the end of the operation using two pledgets on either side of the incision. We do not recommend decompressing the heart using this technique as the risk of bleeding with this vent is much higher compared with the other techniques and it does not offer any advantage over the other much safer techniques.

Decannulation

The right atrium is decannulated first. The pursed string is tied and a further stitch is placed to oversew this and bury the purse string knot. We use a 4/0 braided suture (Ethibond) for the purse string and 3/0 monofilament (Prolene) to oversew it. We believe two different types of sutures should be used for the purse string and for oversewing to prevent slippage on each other.

The aorta can be decannulated while still fully heparinised or after the administration of protamine. We prefer the former as it prevents potential clot formation on the aortic cannula prior to decannulation. Some surgeons decannulate the aorta after the administration of protamine. One advantage of this is that volume can be given during protamine-related vasodilation. However, in our practice, all blood in the pump has usually been transfused prior to aortic decannulation. It is important to ensure that the systolic blood pressure is less than 120 mmHg when decannulating the aorta to avoid aortic dissection. The cannula should be removed while gently snugging on the purse string.

Following decannulation, the inner purse string is tied first (assistant's side) followed by the outer purse string (surgeon's side). It is then oversewn with another stitch (usually a 3/0 monofilament Prolene), burying the purse string knot. This minimises the risk of the knot coming apart.

Chest Closure

Various techniques for closing the chest have been described. A secure way of closing the chest is shown (Figs. 2.2). We have used this technique extensively at our centre in more than 2,000 cases, with excellent results. At least 6 wires have to be passed. The wires should run around the sternum in the intercostal spaces except in the manubrium where it has to be passed through the bone (Fig. 2.2a). Adjacent wires on the surgeon's side are wrapped around each other

(Fig. 2.2b). The wires on the surgeon's side are then pulled towards the assistant's side by the assistant so that the sternum is re-approximated. Alternatively, the surgeon can also pull the wires at the assistant's side towards himself or herself approximating the sternum. Adjacent wires on the assistant's side are then wrapped around each other. The wrapped wires on both sides are then wrapped around each other (Fig. 2.2c). The wrapped wires are then twisted around with a twister, closing the sternum tightly and the ends of the wires are buried.

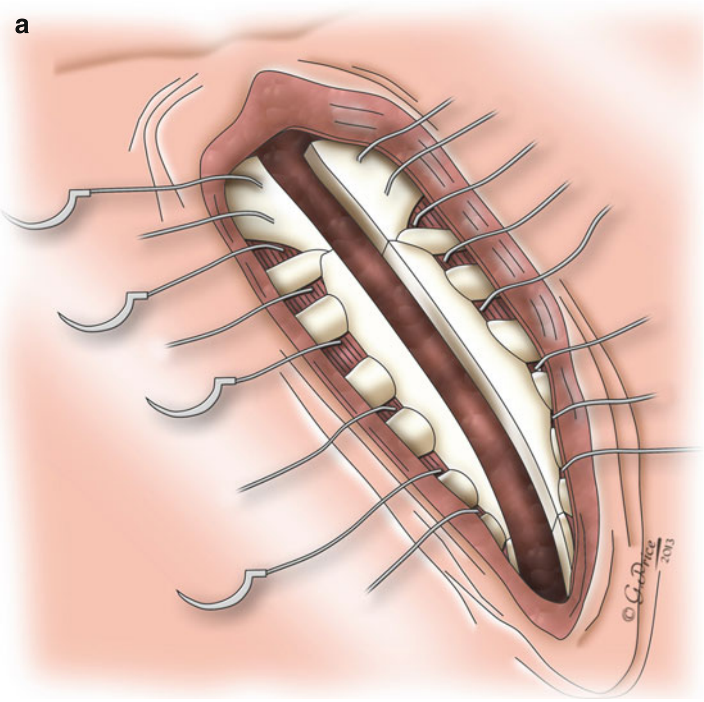

FIGURE 2.2 (**a**) Sternal wires are passed around the sternum (Printed with permission © Gemma Price). (**b**) The sternal wires on the surgeon's side are twisted first (Printed with permission © Gemma Price). (**c**) Sternal wires twisted around each other (Printed with permission © Gemma Price)

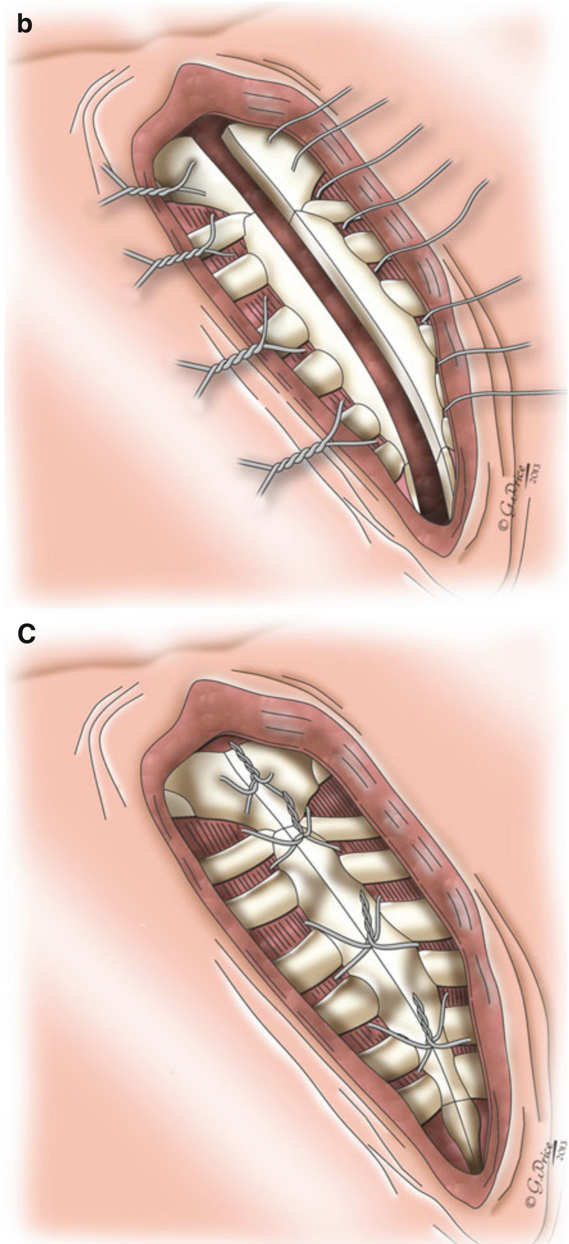

FIGURE 2.2 (continued)

It is important when closing the wound that the muscular layer over the sternum is re-approximated and the dermis closed so as to ensure strong wound healing.

Reference

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Chapter 3
Coronary Artery Bypass Grafting

Prakash P. Punjabi and K.M. John Chan

Introduction

When performing coronary artery bypass grafting (CABG), several decisions need to be made:

1. The coronary vessel to be grafted.
2. The choice of conduit (left internal mammary artery, bilateral internal mammary artery, saphenous vein, radial artery).
3. The site of proximal of anastomosis (aorta, T or Y grafts onto another conduit).
4. The approach (on cardiopulmonary bypass, off pump)

Currently, most surgeons perform CABG on cardiopulmonary bypass although off-pump CABG is also an established approach.

Coronary Vessel to be Grafted

Coronary vessels should be grafted if they have a stenosis of more than 70% (50% if there is left main stem stenosis) or if they are occluded, provided that there is a distal vessel of reasonable size, generally 1 mm or more in diameter. Grafting vessels with only minor stenoses or very small vessels is to be avoided as early graft occlusion will result.

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Choice of Conduit

Traditionally, the left internal mammary artery is grafted to the left anterior descending coronary artery and saphenous veins are grafted to the other coronary arteries. The radial artery is also used, particularly in younger patients with a tight proximal stenosis. Recently, it has been suggested that the use of bilateral internal mammary arteries in young patients may be beneficial.

Harvesting the Left Internal Mammary Artery

The left internal mammary artery (LIMA) is used in almost all cases as it has been shown to have excellent long-term patency and improves survival. The only cases where it is not used is in an emergency situation in an unstable patient where it is necessary to minimise the time of the operation or in very elderly patients.

It can be harvested as a pedicle with the two internal mammary veins on either side of it or skeletonised. We first describe our preferred method of harvesting the IMA as a pedicle.

Pedicle Harvesting of the Internal Mammary Artery

The dissection starts at the distal end of the internal mammary artery (IMA) using diathermy set at 30. The fascia is cut with diathermy about half a centimetre medial to the distal end of the IMA and its vein and parallel to it. The incision is continued for about an inch parallel to the IMA and its vein. Once a plane has been developed, the facia is then pulled downwards and the IMA and its two veins separated from the chest wall by blunt dissection, using the diathermy blade. Any IMA branches are clipped on the artery side and diathermied on the chest-wall side. The distal end of the IMA is then tied off with silk ties and divided, leaving a reasonable length of silk tie attached to the IMA. Gentle traction is applied to the silk tie, pulling the IMA superiorly towards the head. A point diathermy is used, set at 30, cutting the fascia on either side of the IMA and its veins. This frees up the IMA and its veins. The IMA branches are diathermied close to the chest wall. The IMA and its veins are harvested past the first IMA branch until its junction with the subclavian artery. It should lie freely in the chest. The IMA is then placed on a wet swab and papaverine applied to it. Any branches are then clipped. Harvesting of the IMA can usually be completed in about 10–15 min using this technique. It is safe and there is minimal contact with the IMA during harvesting. The important principle using this technique is to get into the right plane where the IMA and its veins are relatively free of the fascia.

Conventional Method to Harvest the Internal Mammary Artery

A more conventional method to harvest the IMA is not to divide it until the end. The initial dissection on the fascia parallel to the IMA and its vein is continued all along its length. The vein and then the IMA are then dissected off the chest wall using blunt dissection with the diathermy blade. Any IMA branches are clipped on the artery side and diathermied on the chest-wall side. A disadvantage with this technique is there is more contact between the diathermy blade and the IMA during the blunt dissection to separate it from the chest wall, thus, increasing the risk of trauma to the IMA. It is also a much slower technique.

Skeletonised Internal Mammary Artery

The IMA can be harvested as a skeleton, i.e. without its two surrounding veins and fascia. An incision is first made with diathermy parallel to the IMA and its vein about an inch along its length and about half a centimetre medial to it. The fascia is then pulled downwards leaving the vein attached to the chest wall, but pulling the IMA off the chest wall. Branches on the IMA are clipped on both the IMA side and the chest-wall side and cut with scissors. The dissection is continued all along the length of the IMA. This method of harvesting the IMA is more challenging and there is increased risk of trauma to the IMA. The advantages of it are an increased length of the IMA and also possibly preservation of the blood supply to the sternum, which may reduce the risk of wound infections in obese diabetics, particularly if the right internal mammary artery is also harvested.

Harvesting the Radial Artery

Before harvesting the radial artery, it is important that an Allen's test has been performed before surgery to ensure that there is reasonable flow through the ulnar artery. The radial artery is always harvested as a pedicle with its two surrounding veins. The radial artery is very prone to vasospasm and, so, there should be minimal handling of it. The radial artery is held via its two surrounding veins and not directly. Previous attempts at harvesting the radial artery as a skeleton has resulted in early occlusion due to vasospasm.

The radial artery pulse is located proximally and distally. The skin incision is made, starting from the distal radial pulse just proximal to the skin crease at the wrist and then extending proximally, medial to the brachioradialis, ending just before the elbow crease. The fat and then the fascia attaching the brachioradials to the pronator teres and flexor carpi radialis are divided. Once this fascia is divided, the radial artery is easily seen and lies free in areolar tissue. It is then grasped via its vein on either side. Any branches are clipped on the radial artery side and diathermied on the arm side. Depending on the length of the conduit required, the radial artery can be harvested until its junction with the brachial artery, i.e. just before the origin of the ulnar artery with the brachial artery.

Harvesting the Saphenous Vein

Conventional Technique

The saphenous vein is usually harvested from the ankle and continued upwards. The vein is identified just above the medial malleolus. The skin above it is cut and the vein freed from the enclosing facia. Any branches are tied and then divided. Depending on the length of conduit needed, the entire vein can be harvested up to the groin.

Use of Stripper

The stripper can be used to minimise the length of the skin incision on the leg and, hence, reduce wound infections and the time for recovery. The incision is usually begun in the groin and the proximal end of the saphenous vein is ligated at the sapheno-femoral junction, keeping a reasonable length of silk tie attached to the saphenous vein. The tissue surrounding the vein is freed by blunt dissection such that the saphenous vein lies free. The vein is then passed into the stripper which is advanced distally until some resistance is met. This corresponds to the position of saphenous vein branches. A 1-cm incision is then made in the skin above where the end of the stripper is. The vein is brought out through this incision, the branches are ligated and divided and the stripper placed again into the vein through this incision and advanced further distally.

Use of the stripper requires considerable experience. If too much force is used, especially when resistance is encountered, the branches can be avulsed off the vein, resulting in an unusable vein. Considerable trauma can also result if too much force is used.

Endoscopic Harvesting

Endoscopic harvesting of the saphenous vein is very similar to the use of a stripper. It is usually harvested from the groin or, sometimes, the knee. The use of the endoscope allows direct visualisation of the vein and its branches and so trauma to the vein is minimised. Only two incisions are needed: one at the proximal end and the other at the distal end.

Setup for on-Pump Coronary Artery Bypass

The basic setup is as for any cardiac operation, with cannulation of the aorta and the right atrium. It is advantageous to lift the pericardium up on both sides of the mediastinum to bring the heart into view. The coronary vessels to be grafted and the conduits are checked before the cross-clamp is applied and antegrade cardioplegia given. Topical ice can be used once the heart has arrested. Antegrade cardioplegia is given every 20 min. Alternatively, retrograde cardioplegia can be given. This may be helpful in very severe proximal and left main coronary stenoses. It is also possible to perform the operation by fibrillating the heart and without the use of cardioplegia. The aorta is clamped and the heart is then fibrillated. Each anastomosis should be completed in less than 10 min if this technique is used.

The conduit to be grafted is first prepared. One end of the LIMA is cut, ensuring that the flow through it is good. A bulldog is then placed about midway along its length to stop the flow of blood to allow the anastomosis to be performed. The LIMA is attached to the left upper edge of the sternal incision by a haemostat clip. Using fine Potts scissors, the inferior edge of the LIMA opening is then cut, creating a "V" shaped opening. The superior edge of the LIMA opening may be further cut by fine scissors to create a diamond shape. To prepare venous conduits, an assistant places fine forceps across the vein, occluding it. A pair of scissors then cuts the vein, usually at a slight angle. The vein opening may be further cut at its inferior edge to create a "V" shaped opening. Conduits for the left anterior descending coronary artery (LAD) and the obtuse marginal (OM) coronary arteries are positioned on the left side of the patient, while conduits for the right coronary artery (RCA) and the posterior descending coronary artery (PDA) are positioned on the right side of the patient.

A general principle for positioning the heart is to place small wet swabs underneath it to bring the heart upwards for easy visualisation. Stay sutures are then placed proximal and distal to the intended arteriotomy to ensure a bloodless field. These stay sutures are then placed so that they help to position the heart in the required position. A clip is attached to the end of the stay sutures and a line-clamp is hung through one of the holes of the clip's handle and allowed to hang by the patient's side, thereby, securing the heart in the required position.

Positioning the Heart for Anastomosis of the Right Posterior Descending Coronary Artery (PDA)

The heart is lifted up and four small wet swabs are placed under it to lift it upwards. The heart is then retracted towards the right shoulder to visualise the PDA, one end of which would lie at the 2 o'clock position and the other end at the 8 o'clock position from the operating surgeon's position. A 2/0 Ethibond stay suture is then passed around the PDA, proximal to the intended arteriotomy. It is clipped, pulled towards the right shoulder and a line-clamp passed through one of the holes in the clip's handle and allowed to hang on the patient's side, thus, securing the heart's position and also ensuring a bloodless field. Another 2/0 Ethibond suture is passed around the PDA distally and positioned in a similar way towards the left shoulder.

Positioning the Heart for Anastomosis of the Circumflex Obtuse Marginal Coronary Artery (OM)

The heart is lifted up, pulled towards the operating surgeon and four small swabs are placed under the heart to lift it up. A 2/0 Ethibond suture is passed around the distal end of the intended arteriotomy as described above and pulled towards the operating surgeon, securing the position of the heart. Another 2/0 Ethibond suture is passed around the proximal end of the intended arteriotomy and pulled towards the assistant's side.

Positioning the Heart for Anastomosis of the Left Anterior Descending Coronary Artery (LAD) and the Diagonal Artery

The heart is lifted up and four small swabs are placed underneath it. A 2/0 Ethibond suture is passed around the distal end of the artery and pulled towards the operating surgeon as described above. Another 2/0 Ethibond suture is passed around the proximal end of the artery. If the diagonal artery is also to be grafted, this proximal stay suture is passed around the LAD, proximal to the diagonal artery, and a further stay suture is placed around the diagonal artery.

Performing the Coronary Arteriotomy

The coronary artery is exposed at the site of the intended arteriotomy by cutting the fat and facia at its surface, using a No. 11 blade. Only the centre of the coronary artery at the site of the intended arteriotomy is exposed. If there is excess fatty tissue, a fat retractor can be used to further aid exposure or the fat can be held away by a 5/0 suture. The coronary artery is lifted up at each side with fine forceps and then opened with the No. 11 blade. The arteriotomy is further enlarged with forward and backward cutting Potts scissors.

Performing the Distal Anastomosis

There are several techniques to perform the distal coronary anastomosis. Generally, an 8/0 or a 7/0 polypropylene suture is used for the LAD anastomosis and a 7/0 for the other anastomoses.

A commonly used technique is to start the first suture bite about 2–3 mm from the heel of the conduit, going from outside the conduit to inside and then from inside the coronary artery to outside, then from outside the conduit to inside again, proceeding in this way until past the heel and onto the other side of it. Generally, 3-5 sutures are placed in this way before holding both ends of the suture and the conduit and gently lowering it onto the coronary artery. The sutures are then tightened and the anastomosis continued in a similar fashion, going from outside the conduit to inside and then from inside the coronary artery to outside until the suture meets the initial suture placed. The assistant should gently follow the suture and maintain gentle traction on it to avoid any loose sutures that would result in an anastomotic leak.

Generally, sutures should not be placed too deeply or superficially from the cut edge of the arteriotomy or the conduit to avoid narrowing or tearing through of the suture. In addition, care should be taken at the heel and toe of the coronary arteries to avoid any narrowing of the vessel or suturing of the back wall of the vessel that would occlude its flow. Many surgeons place a suture directly at the heel and toe of the coronary artery. However, it is not necessary to do this and sutures can be placed either side of the heel and toe, which would avoid any risk of occluding the flow through the coronary vessel by inadvertent catching of the back wall of the coronary vessel. A safe technique, particularly in small coronary arteries, is to place a 1-mm probe into the coronary artery before placing sutures at the heel and toe, which would ensure that the back wall of the vessel is not inadvertently caught.

Following completion of the anastomosis, a syringe of cardioplegia or saline can be flushed through the venous grafts to ensure that the flow is good and there is no leakage.

Short Left Internal Mammary Artery or Hyperinflated Lungs

The length of the LIMA is fixed and situations may arise when this is inadequate. This may not be apparent during the cardiopulmonary bypass until after the anastomosis has been performed and the lungs re-expanded. In such situations, the pericardium can be fixed to the left chest wall, superiorly, to reduce or avoid tension on the LIMA (Fig. 3.1). A vertical slit is made in the pericardium, creating a short superior limb and an inferior limb continuous with the rest of the pericardium. The inferior limb of the pericardial slit is lifted caudally and laterally and sutured to a costal cartilage as caudally as possible (approximately two intercostal spaces caudal to its original position and just medial to the lateral margin of the LIMA harvest site), using a 2/0 Ethibond® suture (Ethicon, Somerville, NJ, US) (Fig. 3.1). This manoeuvre pulls the heart anteriorly towards the chest wall and caudally, thereby, reducing the tension on the LIMA-to-LAD anastomosis. It also prevents the hyperinflated lungs stretching the LIMA and exerting tension on it.

Performing the Proximal Anastomosis

The proximal anastomosis is performed once all the distal anastomoses have been completed. The aortic cross-clamp is removed and replaced with a side clamp. The proximal anastomoses can also be performed with the cross-clamp on. The cardioplegia cannula is removed and the hole made by it on the aorta is enlarged using a 3.5-mm hole puncher. Additional holes can be created on the aorta using a No. 11 blade followed by the hole puncher. Should the hole puncher be used more than once, it is important to ensure that any aortic tissue on it is removed prior to its repeat use.

The vein is filled with heparinised blood or saline and the heart lifted up to check the lie and orientation of the venous conduit. A bulldog is applied and the vein is then grabbed with fine forceps at the site where is should be cut to its required length. The vein is then cut at an angle to enlarge it to the same size as the aortotomy. The anastomosis is then performed in a similar fashion to the distal coronary anastomoses.

A method to ensure secure anastomoses is to ensure that the edge of the vein overlaps the surface of the aorta by 1–2 mm and reasonably deep bites are taken on the aorta, spaced evenly.

Size mismatch may occur between the conduit and the aortotomy, more commonly with a radial artery graft or free internal mammary artery grafts (Fig. 3.2a). In such situations, it is important to stop the bleeding without compromising the

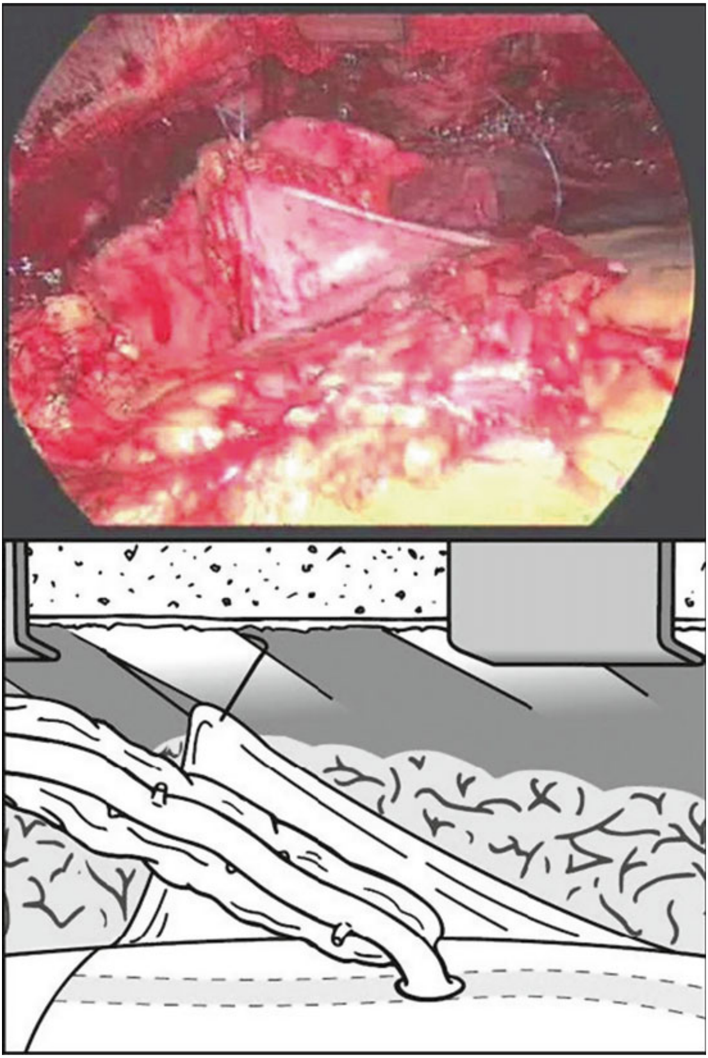

FIGURE 3.1 Securing the left pericardium to the chest wall to reduce or avoid tension on the LIMA-to-LAD anastomosis (Copyright The Royal College of Surgeons of England. Reproduced with permission. Chan et al. [1])

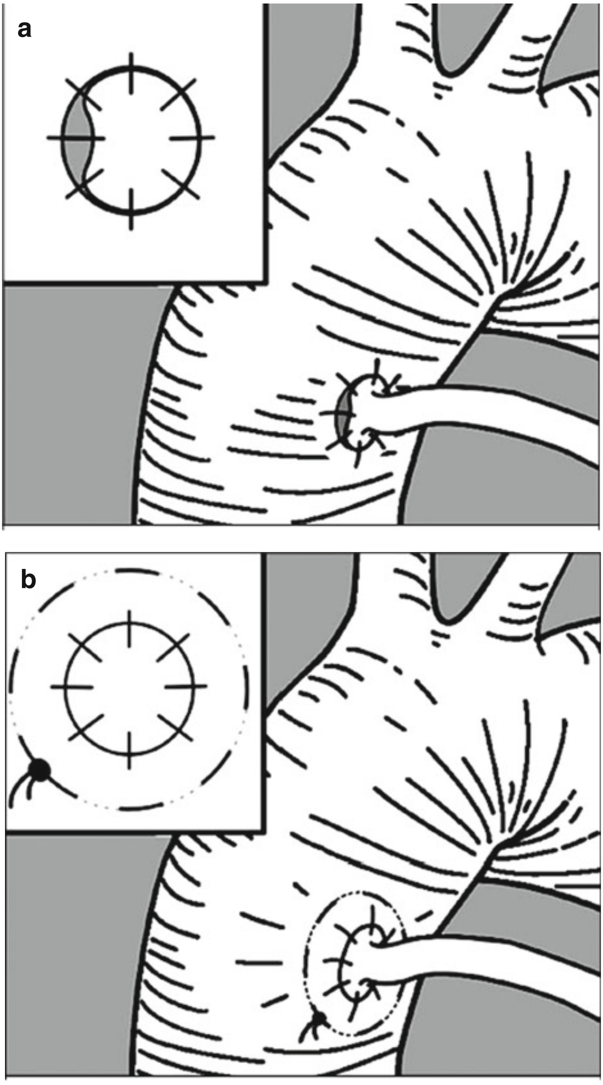

FIG. 3.2 (**a**) Size mismatch between a conduit and the aortotomy causing bleeding (Copyright The Royal College of Surgeons of England. Reproduced with permission. Jarral et al. [2]) (**b**) Purse string suture placed around the aortotomy to reduce its size (Copyright The Royal College of Surgeons of England. Reproduced with permission. Jarral et al. [2])

anastomosis or the blood flow from the aorta to the coronary arteries through the graft. If there is generalised bleeding or ooze around the anastomosis, a separate stitch (6/0 polypropylene) is placed as a separate purse string concentrically around the aortotomy, approximately 5 mm from the anastomotic edge. The perfusionist or anaesthetist is requested to reduce the blood pressure and the purse string is then tied, leading to a reduction of the aortotomy in a uniform style, thereby, causing the bleeding or ooze to stop (Fig. 3.2b).

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Chapter 4
Aortic Valve Surgery

Prakash P. Punjabi and K.M. John Chan

Introduction

The most common indication for aortic valve replacement in the Western world is degenerative calcified aortic stenosis. In developing countries, rheumatic heart disease remains and continues to be an important indication.

Setup

The approach can be a standard sternotomy or a mini sternotomy incision. The ascending aorta should be cannulated as distally as possible, at or above the pericardial aortic reflection, so as to maximise the space available for subsequent placement of the aortic cross-clamp as well as the aortotomy. A single two-stage venous cannula is placed into the right atrium. Cardiopulmonary bypass is commenced. To optimise visualisation during the operation, a vent may be placed through the right superior pulmonary vein via the left atrium and into the left ventricle. The aortic cross-clamp is applied as close to the aortic cannula as possible. In the absence of significant aortic regurgitation, antegrade cardioplegia may be delivered to arrest the heart prior to aortotomy. Retrograde cardioplegia can also be delivered if desired for continued myocardial protection. This may also be helpful in cases of aortic regurgitation.

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Exposing the Aortic Valve

An oblique or transverse aortotomy about 1–2 cm above the origin of the right coronary artery is made. An oblique incision may be extended into the middle of the non-coronary sinus of Valsalva to increase the exposure or to facilitate subsequent aortic root widening. The incision should stop at least 10 mm from the aortic annulus to facilitate easy placement of sutures and closure of the aortotomy. Pump suction is placed through the aortic valve leaflets to remove blood from the left ventricle. Cardioplegia is given at this stage, directly to the coronary ostia if it has not already been given. Typically, 600–800 ml of cold blood cardioplegia is delivered to the left coronary ostia and 250–400 ml to the right coronary ostia. Stay sutures can be placed on the aorta and an assistant can further retract the aortic wall with a leaflet retractor to maximise exposure.

Decalcification and Excision of Leaflet

The aortic valve leaflets are completely excised and can often be removed intact with the attached calcification. Residual calcification on the aortic annulus is then removed with the help of a Ronguers or similar instrument to crush the calcium, followed by the use of scissors and forceps to cut and remove the calcium. In some cases, the use of a scalpel with a No. 11 blade may be helpful. Removal of all calcium deposits is important to allow proper seating of the valve prosthesis and avoid paraprosthetic leaks.

Care must be taken during leaflet excision and decalcification so that the deeper and surrounding structures of the aortic annulus are not damaged. In general, it is safest to leave a 1-mm rim of leaflet tissue during excision. Any remaining calcium deposits can be subsequently removed. Care must be taken not to perforate the aorta, particularly in the region between the commissure of the non-coronary and left coronary leaflet and the middle of the left coronary leaflet. Other structures at risk include the right and left coronary ostia, the anterior leaflet of the mitral valve which lies below the non-coronary sinus and the conduction tissues in the region of the membranous septum around the commissure between the right and non-coronary sinus.

High-powered suction is used throughout the decalcification to remove calcium debris and ensure that these do not enter the coronary ostia or the left ventricle chamber. Placement of a small wet gauze into the left ventricle prior to decalcification can be helpful to catch any calcium deposits which may fall into the left ventricle. A washout with cold saline delivered with a 50 ml syringe is used at the end to flush out and remove any calcium deposits which may have fallen into the left ventricle.

Valve Replacement

The annulus is sized using valve obturators of the desired valve prosthesis. The valve should fit snugly onto the aortic annulus. Too loose a fit would suggest that the patient could benefit from a larger sized prosthesis while too tight a fit would make seating the prosthesis difficult and also risk disruption of the aortic annulus and closure of the aortotomy. In small aortic roots or where patient-prosthesis mismatch may occur, for example, in a large patient with a small aortic root, patch enlargement of the aortic root may be necessary, using either an anterior (Nick's/Nunez, Manouguian procedure) or a posterior (Konno/Rastan) approach.

Suture Placement

The valve may be replaced by using semi-continuous Prolene sutures or interrupted Ethibond sutures, with or without pledgets. Simple interrupted non-pledgeted sutures and non-pledgeted horizontal mattress sutures have the advantage of allowing a larger sized valve prosthesis to be placed, but at a possible risk of increased paraprosthetic leaks. Semi-continuous suturing techniques are also used, which are quicker to perform, but may be less secure than interrupted techniques.

Our preference is to use interrupted pledgeted horizontal mattress non-absorbable 2/0 sutures (e.g. Ethibond) in all patients undergoing aortic valve replacement for degenerative calcification; semi-continuous sutures may be used in non-calcific aortic regurgitation.

The sutures are placed, starting at the commissure between the non-coronary and left coronary leaflets and moving in a clockwise direction along the left coronary leaflet, the right coronary leaflet and ending at the non-coronary leaflet. A double-ended pledgeted suture is used. The needle passes through the annulus with sufficient depth so as to be secure, but care must be taken to avoid injury to deeper structures with a deeper bite of the suture. The suture must pass through annular tissue and not just through leaflet remnants. The mattress sutures are placed appropriately by applying traction to the preceding suture to facilitate visualisation of the aortic annulus for placement of the next suture. Alternating sutures of two colours (e.g. green and white) will help identification of each suture pair. The sutures of each sinus are grouped together to allow easy subsequent placement.

An alternative technique is to place everting horizontal mattress sutures where the pledgets are placed above the annulus rather than below it. This technique has the disadvantage of narrowing the aortic annulus, necessitating the use of a smaller sized valve. However, it may be advantageous if the aortic annulus is large or dilated and it may lower the risk of paraprosthetic leaks. It is also technically easier to perform and avoids the risk of a loose pledget in the left ventricle if the suture breaks, either during placement or knot tying.

Once the sutures have been placed around the aortic annulus, they are then passed through the sewing ring of the valve prosthesis, starting with the sutures from the commissure of the right and left coronary sinus and moving towards the commissure of the left and non-coronary sinus, then with the sutures from commissure of the left and right sinus and moving towards the commissure of the right and non-coronary sinus and ending with the sutures from the non-coronary sinus. Care is taken to ensure equal spacing of the sutures.

Securing the Valve

The sutures are held taut and the valve is lowered into the annulus. The sutures may be relaxed as the valve passes into the aorta and the valve is angled through the aortotomy. The sutures are then pulled taut again while supporting the valve prosthesis to ensure a correct placement on the aortic annulus.

The valve holder is then removed. Sutures are tied, starting at the commissure of the non-coronary and left coronary sinus and moving in a clockwise direction along the left coronary sinus and the right coronary sinus and ending at the non-coronary sinus, following the pattern of placement. Sutures should be tied in a direction parallel to the sewing ring to avoid injury to the leaflet tissue. A minimum of four knots are used. The coronary orifices are inspected to ensure that they are not obstructed by the valve or its struts and the valve leaflets are inspected for optimum opening and closure without obstruction.

Aortic Root Enlargement

If enlarging a small aortic root is felt necessary, a pericardial patch is used. The Nick's/Nunez procedure is generally preferred. The aortotomy is extended downwards through the middle of the non-coronary sinus onto the subaortic fibrous curtain. It is preferable not to include the mitral annulus so as not to affect mitral valve function. A pericardial patch is then used to close this defect, using continuous 3/0 Prolene. The valve prosthesis is stiched onto the pericardial patch using a pledgeted horizontal mattress suture with the knot tied onto the pledget outside the pericardial patch.

Alternatively, the Manouguian procedure can be used. The aortotomy incision is extended downwards through the commissure between the left and non-coronary sinuses into the inter-leaflet triangle and ending just above the anterior mitral leaflet annulus. There is little fibrous support in this region and the edges of the aortotomy can separate widely. The left atrium is dissected away and may or may not be opened. Depending on the degree of aortic root enlargement needed, some or all of the non-coronary sinus can be excised. An appropriate sized pericardial patch, usually about 4 cm in diameter, is used to fill the defect created. A pericardial strip is placed along the incision, outside the aortic wall. Continuous 3/0 Prolene sutures or multiple interrupted horizontal mattress 3/0 Ethibond sutures are then placed through the pericardial strip, the aorta and the patch. If the left atrium is opened, this will need to be closed by suturing to the pericardial patch.

The prosthetic valve is then sutured to the patch using interrupted horizontal matress 2/0 Ethibond sutures with the sutures passing through the patch and tied on the outside, supported by pledgets. The sutures can also pass through the anterior mitral annulus in this region for additional support.

The anterior approach described by Konno/Rastan is generally used in the paediatric population. A longitudinal aortotomy is made and is extended into the right coronary sinus of Valsalva, as far to the right of the right coronary ostia as possible, but not reaching the commissure between the right and non-coronary sinuses and onto the anterior wall of the right ventricle. The ventricular septum is incised. An appropriately sized oval pericardial patch is then sutured on the right ventricular side of the incised septum, continuing up to the level of the aortic annulus using interrupted pledgeted horizontal matress 3/0 Ethibond sutures. The valve sutures are then placed through the patch as a horizontal mattress suture supported by pledgets, with the knot tied on the outside of the patch. A separate continuous 3/0 Prolene suture is used to stich the patch to the aorta, closing the aortotomy. Another patch is then used to close the right ventricular outflow tract. This is sewn onto the edges of the right ventricular outflow tract and across the first patch at the level of the prosthetic valve, using continuous 3/0 Prolene.

Aortotomy Closure

A two-layered closure is used. A double-ended pledgeted 4/0 Prolene suture is used, starting at one end of the aortotomy. An everting horizontal mattress stich is first placed. Both needles are passed through both edges of the aortic wall about 5 mm apart and 5 mm in depth and another pledget is placed through these and the two ends of the sutures are tied down. A rubbershot clip is applied to one end of the sutures while the other end is used to close the aorta. A continuous horizontal mattress suture is used, approximating the two edges of the aortic wall and everting them. The sutures are placed about 5 mm in depth and moved about 5 mm at a time along the aortic wall. This is continued until about halfway along the aortotomy. The procedure is then repeated, using another double-ended suture, starting at the other end of the aortotomy and moving towards the first suture.

If the aortotomy has extended too close to the annulus, it may be necessary to close the aortotomy using a pericardial patch. In such cases, it is better to suture the pericardial patch to the aortic wall before lowering the valve prosthesis onto the annulus. If a pericardial patch is not used, it is advisable to place the first stitch for aortotomy closure first before lowering the valve.

Once the second suture has reached the first suture, the aorta is de-aired. The patient is placed in a head-down position, the anaesthetist is asked to inflate the lungs and hold them in inflation, the perfusionist is asked to fill the heart and the aortic cross-clamp is removed. Forceps can be placed in the space between the two sutures to allow the escape of trapped air. The two sutures are then tied together once deairing is complete.

One end of the suture is then used as a continuous suture towards one end of the aortotomy. The depth of the suture should be above the previous horizontal matress suture. The suture is tied to the suture remaining at one end of the aortotomy and the procedure is repeated for the other side of the aortotomy.

Chapter 5
Mitral Valve Surgery

Prakash P. Punjabi and K.M. John Chan

Introduction

In Western developed countries, mitral valve surgery usually involves degenerative or Barlow's valve disease, causing mitral regurgitation; the mitral valve can usually be repaired successfully. However, in developing countries, rheumatic mitral valve disease, causing mitral stenosis or regurgitation or both, is still common and repairing these valves can be more challenging.

Pre operative transoesophageal assessment of the mitral valve is essential. This is usually performed after the induction of anaesthesia and before the commencement of cardiopulmonary bypass. In most cases, this would confirm the findings of transthoracic echo, but new changes may sometimes be identified.

Setup

Optimal setup is very important in mitral valve surgery to maximise exposure and visualisation of the mitral valve. The pericardium should be lifted up on the right side and left free on the left side. This has the effect of rotating the heart upwards and towards the left, bringing the mitral valve into view when the left atrium is opened. A Cosgrove mitral retractor is used. Further visualisation of the mitral valve is

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enabled by incising the pericardium on top of the SVC and perpendicular to it. This allows retraction of the heart upwards when the retractors are placed.

The aorta, SVC and IVC are cannulated. An antegrade cardioplegia and a retrograde cardioplegia cannula are inserted. Tapes may be passed around the SVC and IVC. Cardiopulmonary bypass is commenced. A cross-clamp is applied. Cardioplegia is delivered antegradely to start with and then every 20 min retrogradely through a self-inflating balloon catheter while suction is applied to the aortic root.

Excision of Left Atrial Appendage

If the patient is in atrial fibrillation and ablation surgery is contemplated, the left atrial appendage is excised at this stage. The heart is lifted up, exposing the left atrial appendage. This is excised with scissors. It is then oversewn with 4/0 Prolene leaving 5–10 mm above the base of the left atrial appendage. Other methods have also been used, such as stapling the left atrial appendage, ligating it from outside, either with a simple silk tie or by placing a purse string suture, or ligating it from inside by placing a purse string around its base and tightening this. However, these other methods have a higher failure rate compared to excision and suture.

Another important step, especially if ablation surgery is to be performed, is to separate out the back of the heart at the oblique sinus from the oesophagus to minimise trauma to it from the energy waves. While the heart is lifted up with the left hand, the fingers of the right hand are placed onto the back of the heart at the oblique sinus to separate it from the oesophagus. This space will fill with blood or water, thus, forming an insulating layer.

Exposing the Mitral Valve

The venous cannulation lines are placed over on the left side, supported by the mitral retractor.

Left Atriotomy

Our preferred approach to the mitral valve is through a left atriotomy. An incision is made midway between the inter-atrial septum and the origin of the right superior pulmonary vein and extended inferiorly along the left atrium towards the left inferior pulmonary vein, ending a few millimetres inferior to it. The incision is then extended superiorly a few millimetres beyond the end of the right superior pulmonary vein onto the roof of the left atrium. This incision is facilitated by the previous dissection on the SVC. Two small mitral retractors are then inserted and lifted up together, opening up the left atrium and exposing the mitral valve.

We have found that this approach to the mitral valve, together with the steps described earlier which free up the heart and allow its rotation, provides excellent exposure to the mitral valve. To improve visualisation of the mitral valve further, the incision can be extended superiorly and medially underneath the SVC and onto the roof of the left atrium.

Transseptal Approach

If surgery to the right side of the heart is also to be performed, e.g. to the tricuspid valve, the transseptal approach can be used. A vertical incision is made in the right atrium from the right atrial appendage to the inter-atrial septum. The septum is then incised at the foramen ovale.

Alternatively, an incision is made in the right atrium parallel to the inter-atrial groove about 2 cm above it. The incision is extended superiorly to the junction with the left atrium. The septum is then incised horizontally at the lower edge of the foramen ovale. It is extended superiorly to join the right atrial incision, continuing onto the roof of the left atrium. The retractor is then placed on the septum or a stay suture is applied to expose the mitral valve.

Assessing the Mitral Valve

A systematic analysis of the mitral valve is performed. The mitral valve is first inspected. Note is made of any excessive leaflet tissue, leaflet perforations, ruptured chordae or ruptured papillary muscles. The lesion is then determined using a pair of nerve hooks (Fig. 5.1). A reference point, such as P1 or the commissures, is chosen. Each part of the mitral valve leaflet is lifted up in turn and compared to the reference point to determine if there is leaflet prolapse or restriction. A variety of techniques can be used to repair the mitral valve, depending on the lesion.

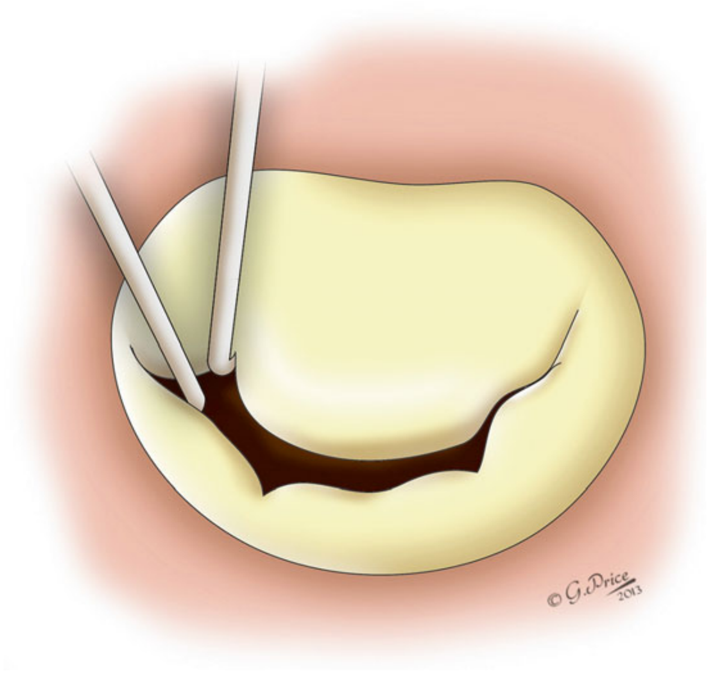

FIGURE 5.1 Assessing the mitral valve using a pair of nerve hooks (Printed with permission © Gemma Price)

Posterior Leaflet Prolapse

Prolapse of the posterior leaflet and, in particular, P2 prolapse is most easily repaired (Fig. 5.2). It may be due to excessive leaflet tissue as in Barlow's disease, chordal or papillary muscle rupture or both. The aim of the repair is to restore the surface of coaptation with the anterior leaflet. This is usually achieved by excision of the prolapsing posterior leaflet.

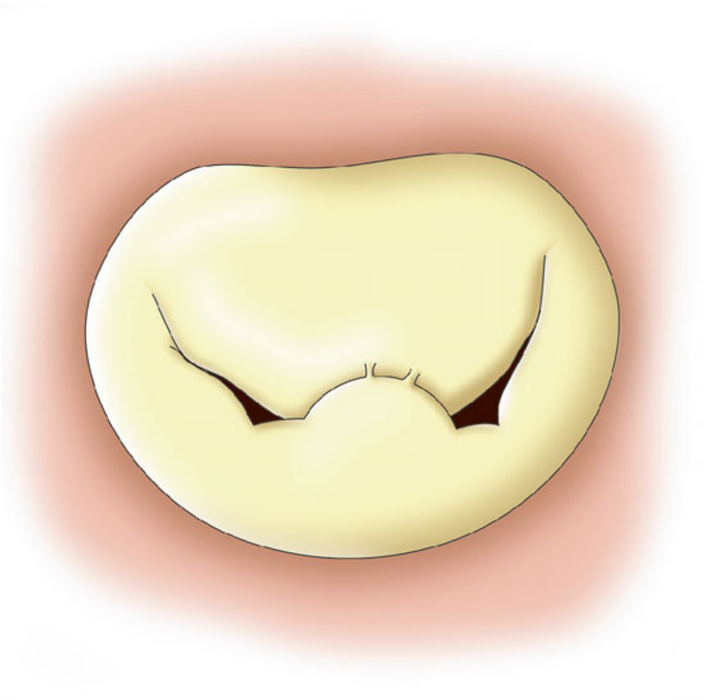

FIGURE 5.2 Prolapse of P2 due to ruptured chordae (Printed with permission © Gemma Price)

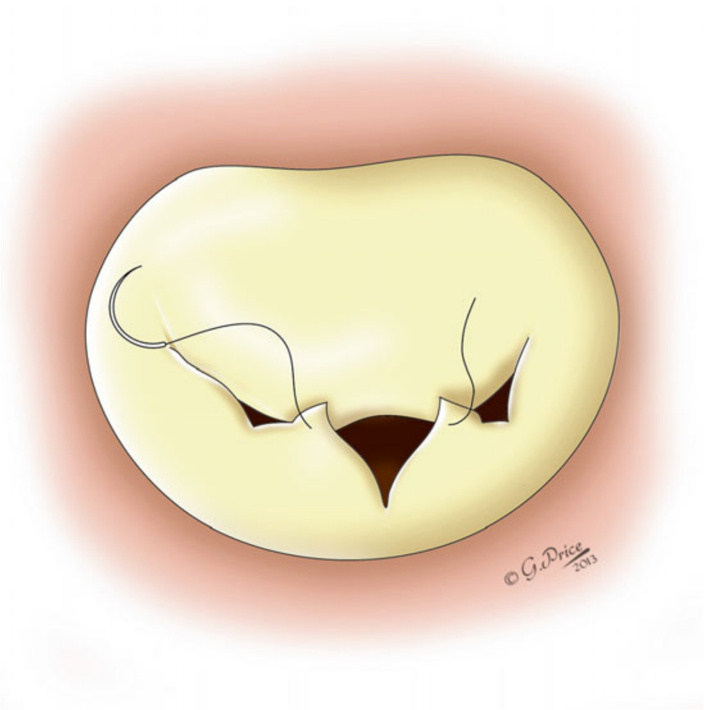

FIGURE 5.3 Triangular resection of P2 prolapse (Printed with permission © Gemma Price)

Triangular Resection

The prolapsed leaflet can be excised in a triangular fashion down to the annulus (Fig. 5.3). The leaflets are then re-approximated using interrupted mattress 4/0 Prolene sutures.

"P" Repair

Our preferred method of posterior leaflet repair is by excising the prolapsing leaflet in a trapezoidal fashion down to the annulus (Fig. 5.4). The remaining leaflets either side of

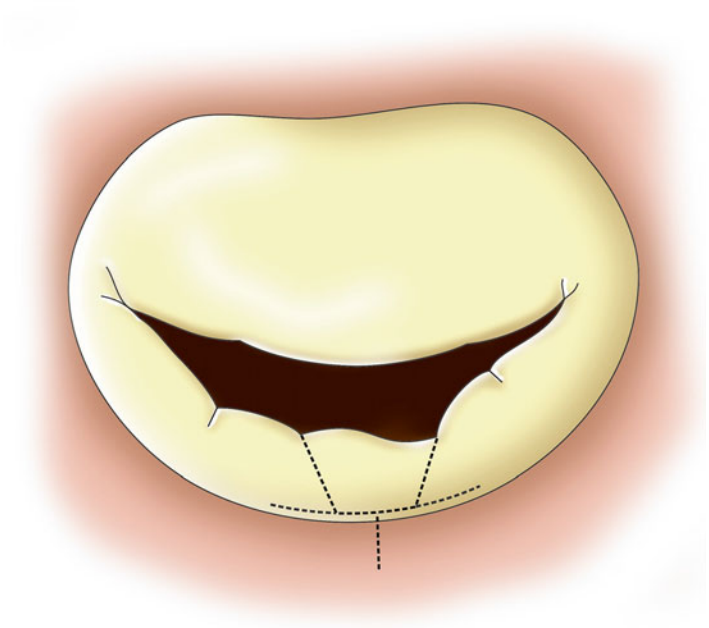

FIGURE 5.4 "P" repair of the posterior leaflet. *Dotted lines* indicate the line of resection (Printed with permission © Gemma Price)

this is incised a few millimetres. This reduces the tension on the annulus and, thus, on the approximated leaflets. It also avoids excessive folding of the annulus when it is approximated and, so, could prevent kinking of the circumflex coronary artery as it passes below the mitral annulus. This is especially important in elderly patients with non-calcified coronary arteries.

The exposed annulus is then approximated using interrupted pledgeted 2/0 Ethibond mattress sutures, starting from the mid-point of the annulus, which needs to be re-approximated. Two sutures are usually needed. The leaflets are then re-approximated using interrupted mattress 4/0 Prolene sutures (Fig. 5.5).

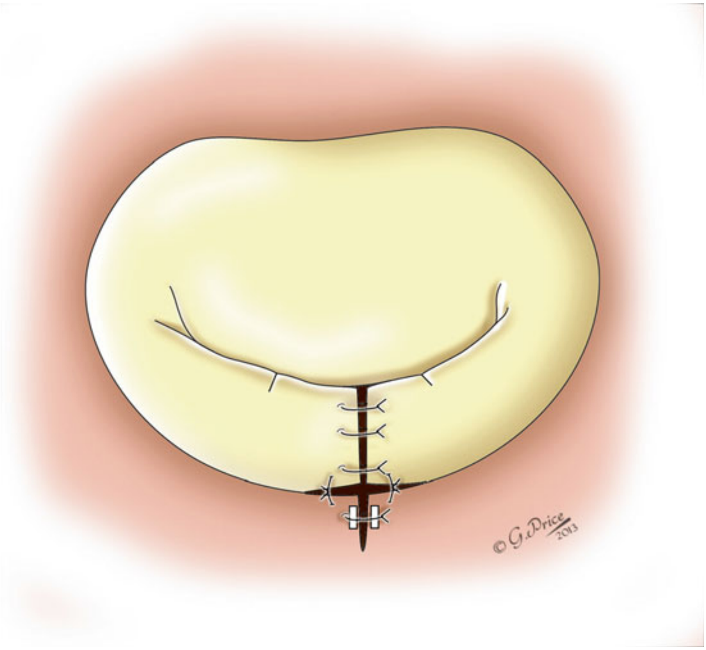

FIGURE 5.5 Completed "P" repair of the posterior leaflet (Printed with permission © Gemma Price)

We have found that the majority of posterior leaflet prolapses can be successfully repaired using this technique. It is easy to perform and is reproducible.

Quadrangular Resection and Sliding Plasty

The prolapsing leaflet can also be excised in a quadrangular fashion (Fig. 5.6). This can be combined with a sliding plasty, especially if there is excessive leaflet tissue which needs to be reduced in height, e.g. in Barlow's disease.

Artificial Neochordae

Artificial neochordae can also be used, especially if there is a large portion of the posterior leaflet prolapsing. The principle

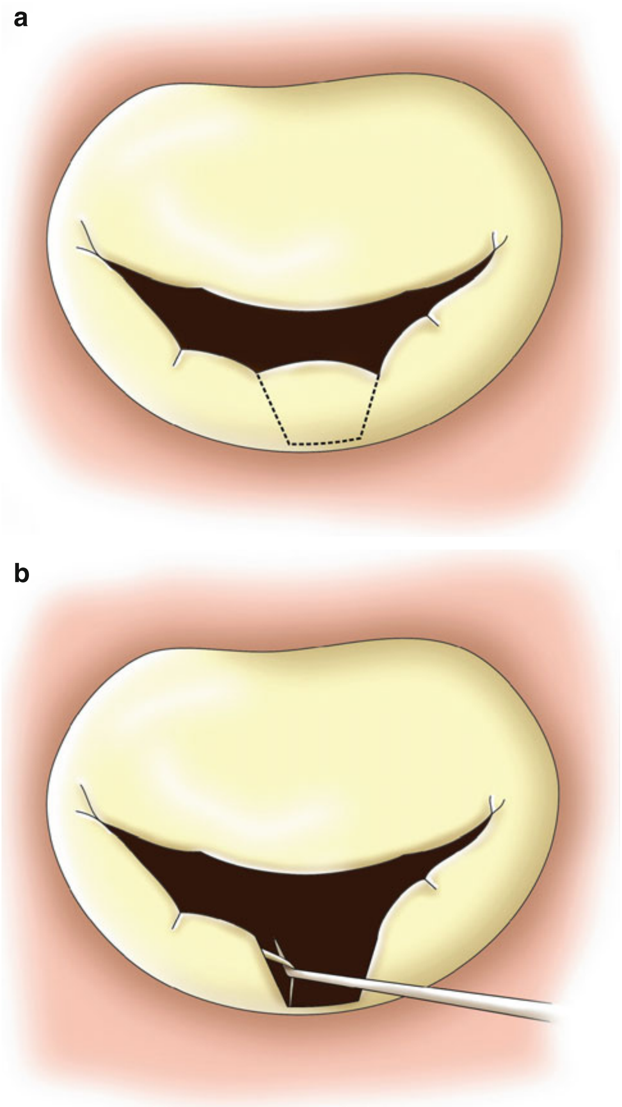

FIGURE 5.6 (**a**) Quadrangular resection of posterior leaflet prolapse. *Dotted lines* indicate the line of resection (Printed with permission © Gemma Price) (**b**) Quadrangular resection of posterior leaflet prolapse (Printed with permission © Gemma Price) (**c**) Quadrangular resection of posterior leaflet prolapse (Printed with permission © Gemma Price)

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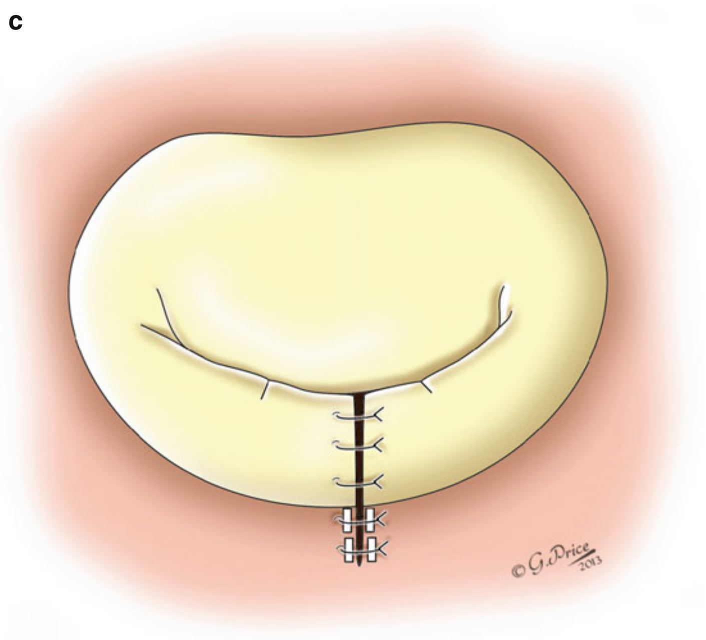

FIGURE 5.6 (continued)

and technique for this are described in the section below on anterior leaflet prolapse. The application of this technique to posterior leaflet prolapse, the so called "respect do not resect" principle, has recently gained popularity.

Anterior Leaflet Prolapse

Prolapse of the anterior leaflet is more challenging. Our preferred method of repairing this lesion is with the use of artificial neochordae. This is usually combined with triangular resection in the case of A2 prolapse. The aim, again, is to restore the surface of coaptation of the prolapsing anterior leaflet with the posterior leaflet. A 5/0 goretex is usually used with Gore-Tex pledgets.

If repair of both the anterior and posterior leaflets are necessary, it is advisable to place the neochordae on the papillary muscles for the anterior leaflet repair before complete repair of the posterior leaflet, as the visualisation is much improved.

Artificial Neochordae

The prolapsing leaflet is determined and the papillary muscle to which the neochordae should be attached is chosen. The pledgeted neochorda is placed through the fibrous tip of the papillary muscle and passed in the direction to which the leaflet is prolapsing. The neochorda is not tied onto the papillary muscle. This ensures equal distribution of tension and length in the two neochordae which are attached to the leaflet from each papillary muscle. The neochorda is passed through the edge of the prolapsing leaflet from below upwards. A pledget is passed through this. The stitch is the passed round the edge of the mitral leaflet and through it and the pledget again so that the length of the neochorda is fairly fixed but can still be adjusted. The length of the neochorda is estimated by approximating the free edge of the anterior leaflet onto the anterior annulus [1].

If repair of the posterior leaflet is necessary, it is performed at this stage. The final length of the artificial neochorda is determined by approximating the free edge of the anterior and posterior leaflets using nerve hooks, ensuring that they both meet in the same place.

We have been able to repair most cases of anterior leaflet prolapse using the above technique. It is an easy technique, is reproducible and has excellent durability.

Use of Native Chords

Other techniques for anterior leaflet repair have been described, such as papillary muscle repositioning and chordal transposition. The principle in these other repair techniques is similar to that using artificial neochordae, but the native chords are used instead of artificial neochorda. Although good results have been reported using these techniques, there is some concern with the use of the native chords, especially in degenerative disease, as these chords are invariably involved in the disease process.

Chordal Transposition

The chords are transposed, either from a normal posterior leaflet (the flip-over technique) or from an adjacent anterior leaflet.

Papillary Muscle Repositioning

In papillary muscle repositioning, the papillary muscle supporting the chords of the prolapsing anterior leaflet is cut vertically. The tip of the cut papillary muscle to which the chords are attached is then attached lower down to the same papillary muscle. The distance moved is equivalent to the prolapsed height of the anterior leaflet, thus, correcting the prolapse. The amount of correction using this technique is limited to the length of the papillary muscle which can be repositioned.

Edge to Edge Repair (Alfieri Stitch)

The principle in this technique is to stitch the prolapsed anterior leaflet onto a normal posterior leaflet opposite it. It can be used on its own in highly selected cases and is sometimes used in combination with any of the techniques described above.

Annuloplasty

We routinely perform an annuloplasty following all mitral repairs. The annuloplasty serves to support the annulus and prevents subsequent dilatation of the annulus. In functional mitral regurgitation due to ischaemia or dilated cardiomyopathy, it also serves to restore the normal size and shape of the mitral annulus.

Band Annuloplasty

Our preferred approach in most cases of degenerative mitral regurgitation is to use a band annuloplasty. The size of the band is determined using the supplied manufacturer's sizers matched against the inter-trigonal distance. It can also be sized by matching the sizers to the anterior leaflet of the mitral valve. The trigone is usually located above the commissures. It is usually seen as a dimple, especially when the anterior leaflet is pulled towards the posterior leaflet.

Interrupted, non-pledgeted, 2/0 Ethibond, horizontal, mattress sutures are placed around the posterior annulus, starting at each fibrous trigone. Care should be taken to ensure that the band is stitched onto the fibrous trigone at each end. This is important, as failure will occur if the band is not anchored to the trigones.

If resection of P2 had been performed with approximation of the annulus, the sutures are tied either side of the approximated annulus and not across it. This avoids excessive tension on the approximated annulus.

We believe a band annuloplasty is preferable to a ring annuloplasty in degenerative mitral regurgitation as it maintains the normal physiological 3-dimensional dynamics of the mitral valve and annulus. For example, during systole, the mitral annulus is known to move towards the apex of the left ventricle and reduce in size while, during diastole, it recoils back towards the left atrium and increases in size. There is also some evidence that, during diastole, pressure on the aortic root may push the anterior mitral annulus inwards, thus, helping to close the mitral valve.

Ring Annuloplasty

A complete ring annuloplasty can be inserted in a similar way to that described for a band annuloplasty. In this case, the sutures are also placed all around the anterior annulus. There are several types of rings available, including rigid rings, semi-rigid rings and flexible rings. Insertion of a complete rigid or semi-rigid ring annuloplasty fixes the size of the annulus in systole and restricts the normal physiological 3-dimensional movement of the mitral annulus. Even a flexible ring would restrict the dynamic movement of the mitral annulus during the cardiac cycle. We, therefore, avoid the use of a complete ring in degenerative mitral regurgitation.

A compete ring annuloplasty may be preferred in cases of functional mitral regurgitation due to ischaemia or dilated cardiomyopathy. In these cases, a rigid or semi-rigid ring which is 2 sizes smaller than the measured size is used. For example, if the mitral annulus is sized at 30, a size 26 ring is used. The mitral annulus in these cases is usually dilated and, in the case of functional ischaemic mitral regurgitation, there is also restriction of the leaflet, usually at P3 and sometimes P2, also. The use of an undersized ring annuloplasty helps to restore the normal mitral annular size and leaflet coaptation. Good long-term results have been reported using this technique.

Newer, specially designed rings can be used for functional ischaemic mitral regurgitation and dilated cardiomyopathy. The Etiologix Carpentier-Adams-McCarthy ring, for example, is designed for use in functional ischaemic mitral regurgitation. This ring specifically undersizes the annulus at P3. The Geoform ring is another of the newer rings designed to over-correct the septal-lateral mitral annular size. It has been used in functional mitral regurgitation due to dilated cardiomyopathy. Although early results from these newer rings appear promising, long-term results on their durability is awaited.

Testing the Valve Repair

The competency of the mitral valve is tested by injecting water or saline through the valve into the left ventricle. The mitral valve should be able to hold a reasonable pressure of water, with no more than trace mitral regurgitation.

The final test of the repair is performed using transoesophageal echocardiography when the patient is off cardiopulmonary bypass with a systolic blood pressure above 100 mmHg. There should be no more than trace mitral regurgitation.

Mitral Valve Replacement

Except for rheumatic mitral valve disease, mitral valve replacement should be performed with preservation of the subvalvular apparatus to both the anterior and posterior leaflets of the mitral valve.

Interrupted, everting, pledgeted, 2/0 Ethibond, horizontal, mattress sutures are placed from the left atrial side so that the pledgets are on the left atrial side. For the posterior leaflet, the stitches are placed through it, such that the leaflet is folded onto itself, maintaining its attachment to the subvalvular apparatus. For the anterior leaflet, the smooth part of it can be resected to reduce its height, taking care not to resect any of the primary chords which attach to the free edge of the leaflet. The stitches can then be placed through the leaflets to re-approximate them again. This maintains the subvalvular apparatus to the anterior leaflet.

Once all the sutures have been placed around the annulus, it is then passed around the valve ring from below upwards so that when the sutures are tied, the knot lies on the left atrial side.

Closure

The left atrium is closed by a single continuous layer of Prolene, starting at either end of the incision.

Reference

1. Punjabi PP, Chan KMJ. Technique for chordae replacement in mitral valve repair. Ann Thorac Surg. 2012;94:2139–40.

Chapter 6
Tricuspid Valve Surgery

Prakash P. Punjabi and K.M. John Chan

Introduction

Surgery on the tricuspid valve generally involves functional tricuspid regurgitation secondary to mitral valve disease. Pre-operative assessment of the tricuspid valve involves determination of the presence of tricuspid regurgitation and/or tricuspid annular dilatation. The most common indication for tricuspid valve surgery is the presence of significant tricuspid regurgitation or tricuspid annular dilatation during mitral valve surgery.

Setup and Approach

The aorta, SVC and IVC should be cannulated and tapes passed around the SVC and IVC. These should be snugged prior to opening the right atrium. The tricuspid valve is approached, either through a vertical or horizontal atriotomy. A vertical atriotomy is performed from the atrial appendage towards the inter-atrial septum while a horizontal atriotomy is performed from the atrial appendage towards the IVC cannula site (Fig. 6.1).

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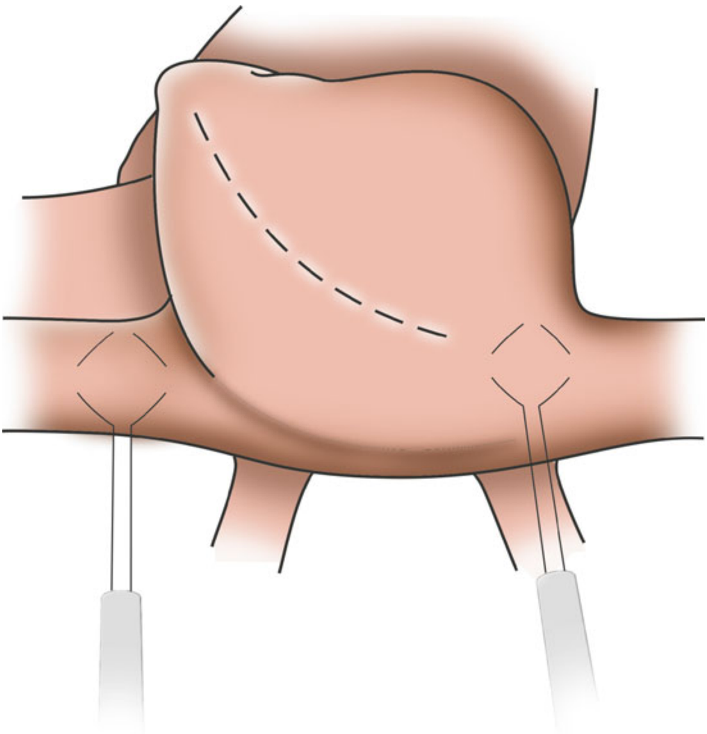

FIGURE 6.1 Horizontal right atriotomy (Printed with permission © Gemma Price)

Assessing the Tricuspid Valve

A systematic analysis of the tricuspid valve is performed. The tricuspid valve is first inspected (Fig. 6.2). Note is made of any excessive leaflet tissue, leaflet perforations, ruptured chordae or ruptured papillary muscles. The lesion is then determined using a pair of nerve hooks. Each part of the tricuspid valve leaflet is lifted up, in turn, to determine the presence of prolapse or tethering. The tricuspid annular diameter is then measured. This is generally taken as the distance between the

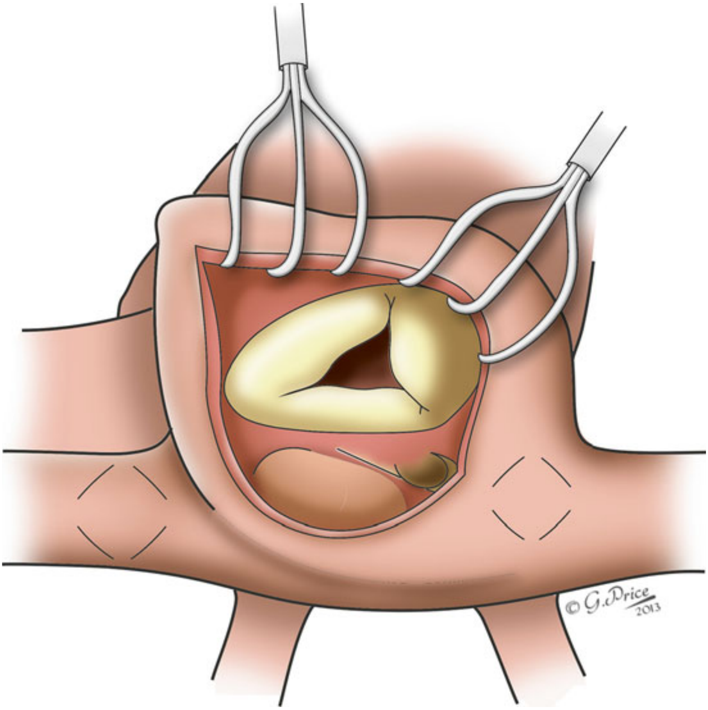

Figure 6.2 Inspection and assessment of the tricuspid valve (Printed with permission © Gemma Price)

anteroseptal commissure and the anteroposterior commissure (i.e. the direction of maximal dilatation). It is considered dilated if it is greater than 70 mm when measured intraoperatively. This corresponds to a diameter of 40 mm when measured preoperatively by transthoracic echocardiography in a four chamber view (which measures the distance from the middle of the septal annulus to the middle of the anterior annulus). Most cases of functional tricuspid regurgitation are due to tricuspid annular dilatation and tricuspid annuloplasty is usually sufficient to address this.

Ring Annuloplasty

Ring annuloplasty is generally preferred if the tricuspid annular dilatation is severe, particularly if associated with tricuspid leaflet tethering. Most tricuspid rings comprise a short linear segment, corresponding to the septal annulus, and a longer curved segment, corresponding to the posterior and anterior annulus. There is usually a gap between the anterior segment and the septal segment of the ring to avoid suture placement in the region of the conduction tissues.

Sizing of the tricuspid annuloplasty ring can be done in several ways. The septal annulus dilates the least in functional tricuspid regurgitation and, so, measurement of its length with a ring sizer can be done to determine the ring size to use. The ring sizer has two notches at its septal segment and a sizer is chosen which aligns, to the anteroseptal and posteroseptal commissures (Fig. 6.3). This should also correspond to the surface area of the anterior and posterior leaflets that are attached to the anterior papillary muscle (Fig. 6.4). Usually, the annuloplasty ring size varies between 30–34 mm for males and 28–32 mm for females.

Interrupted, non-pledgeted, 2/0 Ethibond, horizontal, mattress sutures are placed around the tricuspid annulus. The tricuspid leaflet is gently pulled away from the annulus with forceps to visualise its attachment to the annulus. The first septal suture is placed in the middle of the septal annulus, moving round towards the posteroseptal commissure and ending at the anteroseptal commissure. Sutures are not placed between the anteroseptal commissure and the middle of the septal annulus to avoid damage to the bundle of His. Care should be taken around the region of the anteroseptal commissure to avoid damage to the aortic root.

The sutures are then passed through the sewing band of the selected ring. Sutures at the septal annulus are placed through the sewing ring with equal spacing while sutures at the anterior and posterior annulus are passed through the

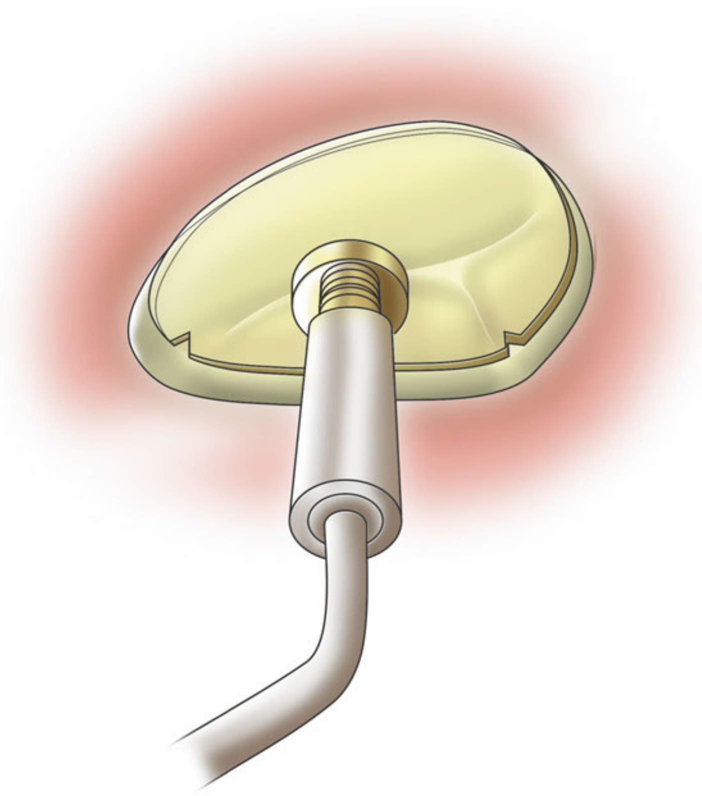

FIGURE 6.3 Sizing the tricuspid annulus with reference to the septal annulus (Printed with permission © Gemma Price)

sewing ring with reduced spacing to achieve a reduction annuloplasty.

The annuloplasty ring is then lowered into position and the knots tied. Valve competency is confirmed by injecting saline through the tricuspid valve into the right ventricle using a 50 ml syringe. The final test of valve competency is done using transesophageal echocardiography after coming off cardiopulmonary bypass.

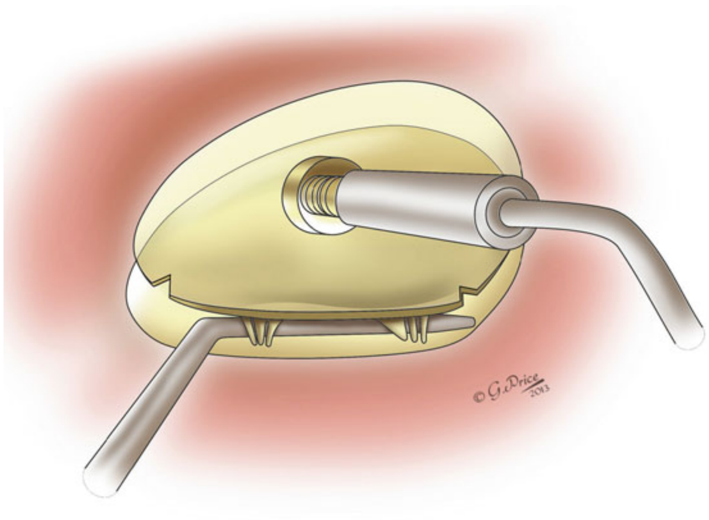

FIGURE 6.4 Sizing the tricuspid annulus with reference to the anterior leaflet (Printed with permission © Gemma Price)

Suture Annuloplasty

Satisfactory results can be achieved with suture annuloplasty if the annular dilatation is not severe and there is no associated tricuspid leaflet tethering. A technique which we have used successfully is to plicate the posterior annulus. A pledgeted, 2/0 Ethibond, horizontal, mattress suture is placed either side of the middle of the posterior annulus. This is tightened and tied, reducing the size of the posterior annulus (Fig. 6.5). Further sutures can be placed adjacent to this to further reduce the size of the tricuspid annulus until valve competency is achieved.

Other techniques of suture annuloplasty include the De Vega annuloplasty, which comprises a single or double circular suture around the tricuspid annulus, and the Kay Annuloplasty, which results in bicuspidazation of the posterior annulus.

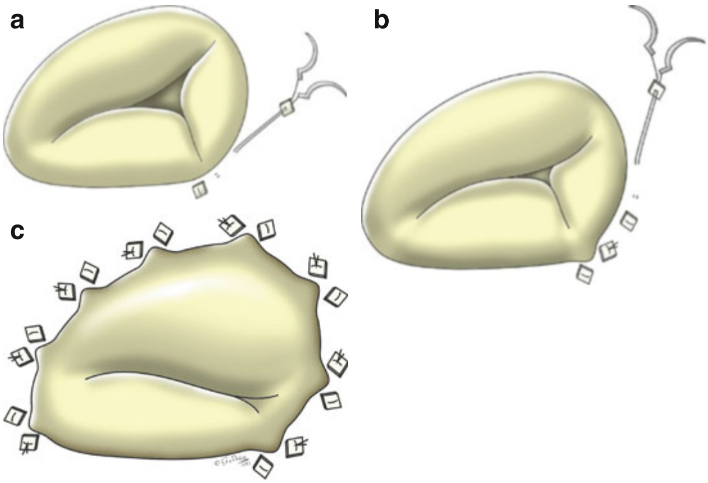

FIGURE 6.5 (**a**) Suture annuloplasty of the tricuspid valve (Printed with permission © Gemma Price) (**b**) Suture annuloplasty of the tricuspid valve (Printed with permission © Gemma Price) (**c**) Suture annuloplasty of the tricuspid valve (Printed with permission © Gemma Price)

Other Repair Techniques

Most techniques described for mitral valve repair can be used in tricuspid valve repair, including leaflet resection and artificial neochordae. In addition, tricuspid leaflet augmentation using autologous pericardium has recently been described for use in severely tethered leaflets.

Closure

The right atrium is closed by a single continuous layer of 4/0 polypropylene, starting at either end of the incision.

Chapter 7
Ascending Aorta and Aortic Root Surgery

Kok Meng John Chan and John R. Pepper

Introduction

Surgery on the ascending aorta and aortic root is indicated for aortic aneurysms, dissections and dilatation of the aorta with bicuspid aortic valves. The diseased aorta is replaced with a prosthetic graft, with or without replacement or repair of the aortic valve.

Cannulation Strategies

The site of cannulation for cardiopulmonary bypass is determined by the extent of the aorta which needs to be replaced. If only the proximal ascending aorta and root needs replacement, cannulation of the distal ascending aorta and right atrium is performed. More often, surgery involves the more distal ascending aorta and the proximal aortic arch. In such cases, cannulation of the axillary artery or femoral artery is necessary. Bicaval cannulation is performed if axillary artery cannulation is used. In some cases, it may be necessary to establish hypothermic circulatory arrest to perform an adequate distal anastomosis to healthy aortic tissue. Cannulation of the axillary artery allows for selective antegrade cerebral perfusion during the period of circulatory arrest. Cannulation of the left carotid artery can be performed, in addition, for

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complete cerebral perfusion. Cannulation of the left subclavian artery may well help to protect against spinal cord ischaemia.

Femoral Artery Cannulation

Cannulation of the common femoral artery is easily performed. However, this technique should be avoided in elderly patients with atherosclerotic aortas or in aortic dissections due to the risk of retrograde embolization and in patients with peripheral vascular disease due to the risk of limb ischaemia.

A 2–3 in. incision is made along the skin crease at the site of the femoral pulse. A vertical incision can also be performed. Dissection is continued until the femoral artery is exposed, both anteriorly and laterally. Care should be taken to ensure that the common femoral artery is exposed proximal to its bifurcation into the superficial femoral artery and the femoral profunda artery where it is of maximal size. Tapes are passed around the femoral artery proximally and distally to allow adequate control of the artery and a snugger passed through the proximal tape. A purse string suture is placed at the femoral artery at the site of the intended cannulation.

Cannulation of the femoral artery is performed by occluding the femoral artery proximally and distally with vascular clamps, incising the femoral artery horizontally with fine scissors and inserting an appropriately sized cannula directed superiorly. The proximal vascular clamp is released to allow passage of the cannula, followed by the distal vascular clamp. Tightening of the purse string suture and the snugger on the proximal tape to the femoral artery and tying this to the cannula secures it in position and prevents leakage. The cannula is then connected to the cardiopulmonary bypass circuit. Femoral artery cannulation can also be performed by the Seldinger technique, inserting a guidewire through a needle into the femoral artery, followed by dilation with a dilator and then, finally, insertion of an extended cannula.

Right Axillary Artery Cannulation

A horizontal incision is made about 1 cm below the middle third of the right clavicle. Dissection is continued to the pectoralis major muscle which is separated in the direction of its fibres. The axillary vein lies immediately anterior to the artery and needs to be retracted with tapes or slings inferiorly. The axillary artery is exposed, both anteriorly and either side of it, to allow passage of vascular loops or small tapes to gain control of it. If selective antegrade cerebral perfusion is planned, the innominate artery is mobilised proximal to its bifurcation with the subclavian and right common carotid arteries so that a cross-clamp can be applied here to maintain perfusion of the right carotid artery during the period of systemic circulatory arrest.

Purse string sutures are placed on the axillary artery at the site of the intended cannulation. The axillary artery is then occluded with vascular clamps or with a side biting clamp, proximally and distally to the site of the intended cannulation. A longitudinal incision is made on the artery with a pair of fine scissors. An 8 mm bevelled prosthetic graft is then sutured onto it in an end-to-side fashion, using a continuous 5/0 polypropylene suture. The prosthetic graft is then cut to about 3 in. in length. A 24 Fr elongated arterial cannula is inserted into it at one end for about 3–4 cm. This will fit snugly into the prosthetic graft. The cannula remains in the prosthetic graft and is not advanced into the axillary artery. The graft is then secured with thick ties onto the cannula, securing it in position and avoiding leakage and the cannula is connected to the cardiopulmonary bypass circuit. An extra limb for arterial perfusion in the cardiopulmonary bypass circuit is advisable in case inadequate flow is achieved through the 24 Fr cannula, in which case, additional cannulation of the aorta or the femoral artery can be performed.

Antegrade perfusion through this cannula achieves perfusion of the right arm and the systemic circulation through the aortic arch. A clamp is placed on the innominate artery during periods of hypothermic circulatory arrest to allow selective antegrade perfusion of the brain through the right common carotid artery. At the end of the operation, following removal of the cannula from the prosthetic graft, the side graft is trimmed close to its anastomosis with the axillary artery and oversewn with continuous 4/0 polypropylene.

Ascending Aortic Aneurysm Replacement

Replacement of an ascending aortic aneurysm limited to the proximal ascending aorta can be performed by placement of a cross-clamp in the proximal aortic arch and construction of the distal aortic anastomosis. If the aneurysm extends more distally, this anastomosis may need to be performed under hypothermic circulatory arrest without a cross-clamp in place. An aneurysm encroaching on the innominate artery may require a hemiarch replacement.

Cardiopulmonary bypass is commenced and a cross-clamp is applied to the distal ascending aorta. Cardioplegic arrest is achieved by cold blood cardioplegia, delivered retrogradely into the coronary sinus. The aneurysm is excised by transecting the aorta proximally about 1 cm above the sinotubular junction and distally about 1–2 cm below the aortic cross-clamp. Care should be taken to avoid injury to the right pulmonary artery, which lies behind the ascending aorta. Further cardioplegia is delivered antegradely directly into the coronary ostia and every 20 min. If necessary, hypothermic circulatory arrest can be performed. The patient is cooled to the desired temperature, depending on whether antegrade cerebral perfusion is used and the extent of surgery planned, and ice bags are placed around the head. Once the desired temperature is reached, the patient is placed in the Trendelenburg position, the circulation is stopped and allowed to drain and the cross-clamp is removed. If axillary artery cannulation is used, a cross-clamp is placed across the innominate artery and flow resumed, achieving selective antegrade cerebral perfusion through the right common carotid artery while maintaining systemic circulatory arrest. To achieve complete antegrade cerebral perfusion, the left common carotid artery can be cannulated, either intra-luminally with a balloon-tipped catheter or, in the standard fashion, with the placement of a purse string suture on the anterior carotid artery wall followed by cannulation with a fine-tipped, right-angled cannula.

The distal aorta is then further trimmed to remove the aneurysm completely until a healthy segment of aorta for the distal anastomosis is achieved. This may need to extend to the level of the innominate artery and the aorta bevelled underneath the aortic arch, in which case, a hemi-arch replacement is necessary.

A prosthetic graft is trimmed and bevelled, if necessary, to match the size and configuration of the distal ascending aorta or arch. It is then sutured to the distal ascending aorta using a continuous 4/0 polypropylene suture, starting from the back wall of the aorta, moving in an anti-clockwise direction and then, with the other end of the needle, in a clockwise direction. Another 4/0 polypropylene suture may need to be used, tied to the initial suture, if the length is inadequate.

The length of the prosthetic graft required is then determined and the graft trimmed to an appropriate length. Excessive length will result in kinking while inadequate length will result in excessive tension and these problems should be avoided. If hypothermic circulatory arrest is used, the patient is now placed in the Trendelenburg position, systemic circulation is recommenced and, after appropriate de-airing procedures, a cross-clamp is placed on the distal prosthetic graft and full cardiopulmonary bypass flow is re-established. The patient is then rewarmed while the proximal anastomosis is constructed. Areas of significant bleeding on the distal anastomosis are now identified and stopped with additional interrupted sutures, which may be pledgeted, if necessary.

The proximal end of the aortic prosthetic graft is now sutured onto the sinotubular junction in a similar fashion to the distal anastomosis, using continuous 4/0 Prolene sutures. Once the anastomosis is completed, the aortic cross-clamp is removed. The anastomosis is checked and any areas of significant bleeding are reinforced with interrupted sutures, which may be pledgeted, if necessary.

Ascending Aortic Dissection

Cannulation of the right axillary artery is preferred in aortic dissection to avoid cannulation of the false lumen, unless this is also involved by the dissection. Cannulation of the femoral artery is avoided due to the risk of false lumen cannulation and retrograde embolization of aortic wall thrombus and atherosclerotic debris, unless the patient is unstable and expeditious cannulation and commencement of cardiopulmonary bypass is necessary. Direct cannulation of the distal ascending aorta can also be performed through the left ventricular apex and the aortic valve. The heart is lifted up and the left ventricular apex incised. An extended cannula is inserted, which is steered towards the aorta and passed through the aortic valve into the ascending aorta. Its position is confirmed by transoesophageal echocardiography and by direct palpation of the ascending aorta. An advantage of this technique is that cannulation of the true lumen is assured and antegrade flow is achieved. This technique assumes the use of hypothermic circulatory arrest. The cannula is removed once the patient is cooled to the required temperature and hypothermic circulatory arrest commenced. Antegrade cerebral perfusion can be performed by direct cannulation of the arch vessels' lumen with balloon-tipped catheters.

An alternative method of cannulation in ascending aortic dissections is by cannulation of the distal ascending aorta by the Seldinger technique, with a guidewire inserted through a needle into the true lumen, guided by transoesphageal echocardiography followed by an extended cannula. The flow situation in an acute aortic dissection is unpredictable so it is well to have a portfolio of cannulation techniques in one's mind to deal with any and every eventuality.

After commencement of cardiopulmonary bypass, a cross-clamp is placed in the distal ascending aorta or, if hypothermic circulatory arrest is planned, the circulation is stopped. The dissected proximal ascending aorta is excised about 1 cm from the sinotubular junction and 1–2 cm from the aortic cross-clamp. The site of the intima tear is located. The extent of the dissection is determined, both proximally and distally.

In most cases of ascending aortic dissections, the distal anastomosis is performed under hypothermic circulatory arrest with the cross-clamp off. A hemi-arch replacement may be necessary in some cases. The aortic arch should be inspected for any evidence of an intimal tear. Replacement of the aortic arch may be necessary if the intimal tear is found in the aortic arch, with individual anastomosis of the prosthetic graft to the left subclavian, left carotid and innominate arteries. In such cases, an elephant trunk technique can be used for later replacement of the descending aorta. Such surgery should only be performed by experienced aortic surgeons in centres with high-volume aortic surgical reconstructions.

Bioglue is used to re-approximate the dissected aortic layers. It is vital to ensure that no glue enters the true lumen as this may well give rise to cerebral emboli. The technique of anastomosis is similar to that described above for replacement of the ascending aorta for aneurysms.

Once the distal anastomosis is constructed, the aortic cannula is placed in the prosthetic graft. Cardiopulmonary bypass is then recommenced, de-airing manoeuvres performed and the cross-clamp applied to the proximal prosthetic graft before full cardiopulmonary bypass flow is re-established.

If the aorta below the sinotubular junction is not involved by the dissection, an ascending aortic replacement is performed, otherwise an aortic root replacement is necessary if the dissection involves the coronary sinuses.

Aortic Root Replacement

Aortic root replacement is indicated for aneurysms, dissections or dilated ascending aortas with bicuspid aortic valves. The diseased portion of the ascending aorta is excised down to the sinuses, leaving about 5–6 mm of aortic tissue above the annulus. The left and right coronary arteries are partially mobilized. Complete mobilization is performed once the prosthetic graft is in place and sutured in place to optimise its position and orientation and avoid any twisting or kinking.

The aortic annulus is sized and a valved composite graft, porcine aortic root or aortic homograft is selected as appropriate. If a homograft is used, this is first cut to the required shape and size. The proximal bottom end is shaped into a scallop to resemble the shape of the aortic annulus.

Simple, interrupted, 4/0 Ethibond sutures are passed though the aortic annulus and through the sewing ring of the prosthesis, starting in the left coronary sinus and proceeding in a clockwise direction. The valved composite prosthesis or porcine root is lowered onto the aortic annulus and the sutures tied down, starting from the left coronary sinus and moving in a clockwise direction. Interrupted, horizontal, mattress sutures can also be used.

The left coronary button is fully mobilised. The button should be of adequate size with about 2 mm of aortic wall to facilitate easy anastomosis. If a prosthetic graft is used, it is incised opposite the coronary ostia to create an opening which is then enlarged. If a porcine root or homograft is used, the left coronary stump is removed and enlarged. The left coronary button is anastomosed using continuous 5/0 polypropylene, starting from its inferior rim and moving in a clockwise direction with one needle and in an anticlockwise direction with the other needle. The right coronary anastomosis is next fully mobilised. If a porcine root is used, a separate opening to the coronary stump of the porcine root prosthesis is necessary as it does not usually align with the patient's right coronary artery. Reasonable bites of the Dacron graft, porcine root or homograft should be taken.

If a porcine root or aortic homograft is used, it can be further anastomosed to a prosthetic graft at its distal end, if necessary, to enable the replacement of an appropriate length of ascending aorta.

Valve-sparing Root Replacement (Yacoub Remodelling Technique)

Valve sparing root replacement is performed in aortic aneurysm surgery when the aortic valve leaflets are normal and the aortic valve annulus is not dilated. The setup is similar to aortic root replacement. The diseased aorta is excised, leaving a 3–5 mm rim of tissue above the aortic annulus and around the coronary buttons which are partially mobilised. The aortic valve is inspected to determine if it can be repaired. The leaflet cusps should be normal and the aortic annulus should not be dilated or the leaflets appearing stretched with little coaptation. Any aortic regurgitation is caused by separation of the commissures due to the aortic aneurysm.

The leaflet height is measured. The aortic annulus is sized using a tube-shaped obturator and a prosthetic graft which is slightly larger is selected. Usually, a 30 mm graft is required in large adults. Alternatively, stay sutures are placed on each of the commissures and traction applied upwards until optimum coaptation of the cusps is achieved. The distance between the commissures at this position is measured. This is roughly one-third the circumference of the required graft.

The graft is cut at three points to match the commissures of the aortic valve and shaped to match the aortic sinuses of Valsalva in depth and width. The cut on the graft usually extends at least nine rings into the graft or at least one and a half times the height of the commissures. It can be further trimmed later, as required.

The three commissures are sutured to the corresponding apices of the cuts on the graft, using 4/0 polypropylene, with the suture passing from inside the graft to the outside. Care is taken to ensure that the orientation is exactly in the long axis of the graft, with no distortion. The graft is then lowered into position and the sutures tied, with the knots on the outside. The excess graft at the sinuses can be trimmed at this stage.

The graft is then sutured to the remnant of the aortic valve sinus, using continuous 4/0 polypropylene, starting from the middle of the sinus and moving towards each of the two commissures which had been sutured to the graft. The needle is passed outside the graft on reaching the commissure and the suture tied to the commissural stitch. This suture line needs to be haemostatic and, so, care is taken to ensure that there is good apposition between the annulus and the graft, without any irregularities. Additional interrupted sutures are used, if necessary, to close any potential leakage areas as this is inaccessible after the operation.

The left coronary ostia is then fully mobilised and an opening made in the graft opposite the coronary button, using thermal cautery as previously described. It is anastomosed to the opening in the graft, using continuous 5/0 polypropylene. This is repeated for the right coronary ostia. The graft is then trimmed to the required length distally and anastomosed to the distal ascending aorta, using continuous 4/0 polypropylene.

The Yacoub technique is associated with a higher rate of late failure at 10 years than the David procedure. It should probably not be used in patients under the age of 40 years as the annulus often dilates in these younger patients.

Valve-sparing Root Replacement (David I Reimplantion Technique)

The setup is similar to that described for the aortic remodelling operation. However, as the prosthetic graft will be seated outside the aortic root and below the aortic annulus, it is important that this area has been adequately dissected and mobilised. The aorta is dissected off the pulmonary artery, right ventricular outflow tract and the left atrium. A horizontal, mattress, pledgeted, 4/0 Ethibond suture is placed in the middle of each sinus of Valsalva at its nadir and passed outside the aortic root. The aortic annulus is sized and a prosthetic graft which is about 5 mm larger than this is chosen. The graft size is usually 32–38 mm. A graft with pre-shaped sinuses of Valsalva, such as the Valsalva graft, is preferred. This is trimmed so that there are two to three rings below the lower re-enforced collar. Each of the three horizontal, mattress sutures are passed through the lower end of the graft and the graft lowered into its position on the aortic root below the annulus. After checking that all of the aortic wall is within the graft, the sutures are tied. This secures the graft in position.

Each commissure is next secured to the graft at its distal re-enforced collar, using horizontal, mattress, 5/0 polypropylene sutures passed from the inside to outside, with the suture tied on the outside. It is important that each of the commissures are sutured to the graft at the same height. The rim of Sinus of Valsalva tissue is next sutured to the graft, using continuous 4/0 polypropylene, starting at the nadir and moving towards the commissure at either side. The needle is passed to the outside at the commissures and the suture tied to the commissural stitch. The valve is now tested for competency and the leaflets inspected to ensure adequate coaptation with no prolapse. Should a leaflet cusp be found to be significantly prolapsed or not coapting with the other leaflets on the same plane, consideration should be given to repositioning the corresponding commissure to either stretch or relax the leaflet, as necessary. Lesser degrees of prolapse can be corrected by doubly running a 6/0 polytetrafluoroethylene (Gore-Tex) suture along its free edge, with the needle passing outside the graft, and re-enforced by a small pledget. Tightening this suture pulls the free margin of the leaflet upwards to the level of the other two leaflets. The suture is tied at the required length when the prolapse has been corrected.

The right and left coronary buttons are next fully mobilised and anastomosed to the graft, as described previously. The operation is completed by anastomosing the distal end of the graft to the aorta, as previously described.

It is essential that high quality intra-operative transoesophageal echocardiography is available throughout these operations.

Chapter 8
Cardiac Tumours

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Introduction

Atrial myxomas are the most common cardiac tumours in adults. They are usually found in the left atrium, but also occur in the right atrium. They are usually friable with a risk of embolization and may obstruct the mitral valve. Other common cardiac tumours in the adult include lipomas and papillary fibroelastomas. Once diagnosed, surgery is usually performed urgently due to the risk of embolization and obstruction to flow. However, if cerebral embolization has already occurred, surgery is usually deferred for a week.

Primary malignant cardiac tumours are very unusual in adults, but pose a technical challenge as they are characteristically infiltrative and often invade adjacent structures. More complex reconstruction of the atrium and adjacent structures may be necessary in these cases if surgery is performed. The most common primary malignant cardiac tumours are sarcomas.

Setup

The setup is similar to mitral valve surgery. A mitral retractor is used. Manipulation of the heart should be kept to a minimum before excision of the tumour to reduce the risk of

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embolization. The pericardium should be lifted up on the right side and left free on the left side. The pericardium is incised on top of the SVC and perpendicular to it, allowing retraction of the heart upwards when the retractors are placed.

The aorta, SVC and IVC are cannulated. An antegrade cardioplegia and a retrograde cardioplegia cannula are inserted. Tapes are passed around the SVC and IVC. Cardiopulmonary bypass is commenced. A cross-clamp is applied. Cardioplegia is delivered antegradely to start with and then every 20 min retrogradely through a self-inflating balloon catheter while suction is applied to the aortic root.

Accessing the Tumour

Atrial myxomas can arise anywhere in the atrium, but usually at the inter-atrial septum adjacent to the fossa ovalis.

Left Atriotomy

Our preferred approach to a left atrial myxoma is through a left atriotomy. An incision is made midway between the inter-atrial septum and the origin of the right superior pulmonary vein and extended inferiorly along the left atrium towards the left inferior pulmonary vein, ending a few millimetres inferior to it. The incision is then extended superiorly a few millimetres beyond the end of the right superior pulmonary vein onto the roof of the left atrium. This incision is facilitated by the previous dissection on the SVC. Two small mitral retractors are then inserted and lifted up together, opening up the left atrium and exposing the inter-atrial septum to which the tumour is attached.

Right Atrial Approach

Right atrial myxomas are approached through a right atriotomy. Left atrial myxomas can also be approached through a right atriotomy. A vertical incision is made in the right atrium from the right atrial appendage to the inter-atrial septum. Alternatively, an incision is made in the right atrium parallel to the inter-atrial groove about 2 cm above it. The incision is extended superiorly to the junction with the left atrium.

Excising the Tumour

An incision is then made in the atrial septum at the fossa ovalis away from the point of attachment of the tumour. A small incision is initially made and then developed around the point of attachment of the tumour, with a sufficient margin of clearance. The tumour should be removed intact, if possible. The area should then be irrigated with saline and suctioned to remove any debris from the tumour. Cardiotomy suction should be avoided once the tumour is exposed until the tumour has been removed and the area irrigated as distant metastases have been reported after surgical removal of myxomas.

Depending on the size of the defect created on the atrial septum, it can either be closed directly or by suturing a pericardial patch to it using continuous 4/0 polypropylene.

Closure

The left or right atrium is closed by a single continuous layer of Prolene, starting, at either end of the incision.