HEART REVIEW

Surgical reconstruction of the mitral valve

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From Cutler's first attempt to treat the mitral valve by inserting a tenotomy knife through the left ventricle, to Carpentier's introduction of several repair techniques and a functional classification for assessing mitral valve lesions, the history of mitral valve treatment is exciting. Mitral diseases may be degenerative, ischaemic, infective or rheumatic, with or without superimposed impaired left ventricular function and calcification. Understanding the underlying pathological features is also important in determining whether mitral valve repair is feasible, how the valve should be repaired and the prospect for long-term durability of the repair. Recent advances in minimally invasive mitral valve surgery are promising but more effort is needed to ensure timely mitral valve repair.

annulus and left ventricular (LV) wall. The annulus is D-shaped with reduced eccentricity in diastole, with the posterior annulus amounting to around two thirds of the overall mitral annulus. Both left atrial and LV size and pressure influence the variation of the annular area during the cardiac cycle.

AETIOLOGY OF MITRAL VALVE DYSFUNCTION

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Degenerative disease

A degenerative mitral valve, also known as "floppy mitral valve", is the most common cause of mitral regurgitation (MR) in the Western world. The long-term mechanical strength of the myxomatous tissue has been of concern, but it is the subset that is most suitable for repair with the best long-term outcome and with the greatest durability in patients with isolated posterior leaflet prolapse.⁵ Ling and colleagues⁶ from the Mayo Clinic also reviewed early surgery compared with conservative management for patients with flail leaflets. They have found improved long-term survival and decreased cardiac mortality and morbidity in the surgical group. Repair of severe degenerative MR has been considered superior to replacement, even in patients with coexisting ischaemic heart disease.⁷

Ischaemic disease

Ischaemic MR does not improve with revascularisation and has been found to be related to mortality in the long term. The best surgical treatment in ischaemic MR, however, is still controversial. Survival rates have been found to be higher in the repair group than in the replacement group.⁸ Elderly patients with impaired LV and renal status and in poorer New York Heart Association functional class, however, had similar survival after either repair or replacement.⁸ Grossi and colleagues,⁹ in a study of 223 consecutive patients undergoing mitral surgery, have advised that the choice between valve repair and replacement depended on the nature of the presentation and pathophysiology of the injury. Replacement may be more reliable in patients with acute MR due to

The mitral valve, so named because of its resemblance to a mitre, a tall bishop's headdress, has an exciting history. In the 1920s, Cutler made the first attempt to treat the mitral valve by using a tenotomy knife inserted through the left ventricle.¹ The patient lived for four and a half years. In 1925, Henry Souttar performed the first finger dilatation of the mitral valve using the transatrial approach.¹ In 1948, Smithy, Harken and Bailey in the United States and Lord Brock in England further improvised the technique of mitral valvotomy.¹ The development of the heart-lung machine made mitral valve replacement, with a variety of prostheses, the standard operation for treating the mitral valve. C Walton Lillehei in 1957 conceptualised annuloplasty for the mitral valve annulus and pioneered the development of mitral valve repair.² Dwight McGoon from the Mayo Clinic in 1960 described triangular resection of a prolapsing segment of the mitral valve caused by ruptured chordae tendineae.³ Carpentier added a gigantic leap to mitral valve repair by publishing in 1983 his seminal paper entitled "Cardiac valve surgery: the 'French correction'".⁴ He not only introduced several repair techniques but also provided a functional classification for the assessment of mitral valve lesions (fig 1). These techniques of surgical repair have continued to be refined and expanded, leading to a resurgence of mitral valve repair.

ANATOMY

The competency of the mitral valve depends on the structural and functional integrity of the various mitral components, namely, anterior and posterior leaflets, chordae tendineae, anterolateral and posteromedial papillary muscles,

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Abbreviations: LV, left ventricular; MR, mitral regurgitation; TOE, transoesophageal echocardiography

Figure 1 Carpentier nomenclature of the mitral valve. Naturally occurring clefts in the posterior leaflet divide it into P1, P2 and P3. Corresponding areas in the anterior leaflet are labelled A1, A2 and A3. The relationship is also shown to the aortic valve (AV), pulmonary valve (PV) and tricuspid valve (TV).

ischaemic or infarcted papillary muscle or severe LV dysfunction. Damage to the subvalvular apparatus may not be easily evaluated during acute injury. Patients with limited rupture of the chordae or papillary muscle tip and those with chronic annular dilatation may, however, benefit from repair.⁹ The most commonly performed technique is the use of an undersized annuloplasty ring. The use of real-time three-dimensional echocardiography has led to better understanding of the geometry of the mitral valve. LV dysfunction without LV dilatation does not seem to have a role in functional MR.¹⁰ The valve has been found to be deformed due to tethering by displaced ischaemic papillary muscles.¹⁰ Its usual saddle shape becomes deformed to a flat shape during ischaemia, ultimately leading to MR. Restoring these localised geometric changes appears to be the preferred approach in the repair of the ischaemic mitral valve. The Carpentier–McCarthy–Adams ring is one such new innovation, designed to deal with asymmetrical dilatation. It is used in type III MR and its asymmetrical curvature is designed to compensate for the tethering of the P3 segment of the posterior leaflet in ischaemic MR.

Infective endocarditis

Urgent surgery is indicated in infective endocarditis if the patient has haemodynamic instability with congestive heart failure, development of abscess or vegetation, resistance to antibiotics, fungal infection¹¹ or an embolic episode.¹² Early surgery should be carried out when, during echocardiography, features of rupture of the chordae tendineae, papillary muscles, sinus of Valsalva or ventricular septum are found.¹² Heart block due to the involvement of the conduction system is another indication for early surgery. Repairing an infected valve has been found to lead to lower hospital mortality and improved long-term outcome compared with replacement.¹³ It must be noted, however, that, intraoperatively, extensive destruction of the subvalvular apparatus and rupture of the chordae can be found in both papillary muscles, which would make repair unsuitable.¹²

Rheumatic fever

Rheumatic disease especially affects children and young adults particularly in the developing world. Because of the progressive damage to the valve, rheumatic fever is considered to carry a higher risk of reoperation than in the

degenerative group. This predisposition to reoperation has been considered to be greater in a younger age group¹⁴ and in patients in the acute phase of inflammation. Chauvaud and associates,¹⁵ however, do not agree that younger age predisposes to reoperation. They also found, in a large series of 951 patients, rheumatic mitral valve repair to have acceptable freedom from reoperation at 10 years and 20 years, along with a low in-hospital mortality.¹⁵ Compared with replacement, rheumatic mitral valve repair has been found to have greater survival benefits.¹⁶ This benefit also extends to patients who have an additional aortic valve replaced when compared with those with both aortic and mitral valve replacement.¹⁷

LV dysfunction

LV function is a significant element in repair, as replacement may cause disruption of the mitral valve apparatus leading to worsening of LV function. Low LV ejection fraction (< 35%) by itself was not a significant risk factor in repair.¹⁸ In the study by Talwalkar *et al*,¹⁸ however, multivariate analysis showed that other risk factors, such as emergency operation, preoperative New York Heart Association class IV and ischaemic heart disease, predicted early and late mortality. Surgical annuloplasty improves symptoms and may also improve survival in patients with MR and advanced chronic heart failure. Repair should also be seriously considered for asymptomatic patients with an ejection fraction > 60%, when the LV end systolic diameter approaches 45 mm.¹⁹ The use of nesiritide (B-type natriuretic peptide) is also being explored in mitral valve reconstruction for patients with severe MR, impaired LV function and pulmonary hypertension, as this drug may contribute to better early outcome.²⁰

Calcification

Valves with severe calcification in both commissures of more than a third of the annulus or of the anterior leaflet with widespread stiff chordae tendineae are considered unsuitable for repair.¹² Where they are repairable, however, valve repair after standard tissue decalcification and debridement of calcified leaflets and annulus does not affect surgical outcome.²¹

CLASSIFICATION OF MR

Carpentier classified MR on the basis of the range of leaflet motion in echocardiography, as table 1 and fig 2 show.

DIAGNOSIS

Echocardiography

Transthoracic echocardiography and transoesophageal echocardiography (TOE) with adjuvant colour flow Doppler are used to assess the components of the mitral valve. The extent of calcification, systolic and diastolic annular dimensions, LV function and the status of other valves are also assessed. Stress echocardiography in the form of exercise or dobutamine is useful in assessing the extent of MR as well as pulmonary artery pressure. High risk patients with latent LV dysfunction may be identified before surgery. Real-time three-dimensional echocardiography is also emerging as a valuable adjunct in assessing the mitral valve, showing the three-dimensional relationship of various mitral structures and accurately measuring cardiac chamber volume and myocardial mass. Malalignment of papillary muscles and narrowing or widening of the interchordal angle can also be visualised.

Angiography

Angiography to assess the status of coronary arteries is usually performed in patients at risk of ischaemic heart disease.

Table 1 Carpentier's classification of mitral regurgitation

Functional type	Pathomorphology	Leaflet motion	Regurgitation jet
I	Annular dilatation Leaflet perforation Dilated left ventricle	Normal	Central
II	Chordal rupture/elongation Papillary muscle rupture	Excessive (either leaflet prolapse)	Eccentric
III	Commissural fusion Leaflet thickening Chordal fusion/thickening	Restricted (usually seen in rheumatic or ischaemic disease)	Eccentric

SURGICAL INTERVENTION

Indications for surgery

Figure 3 summarises the indications for mitral valve surgery.

Symptomatic patients with severe MR and repairable valve should be offered reconstructive surgery. On the other hand, asymptomatic patients with atrial fibrillation or pulmonary hypertension, or with LV ejection fraction ≤ 60 or LV end systolic dimensions of ≥ 45 mm, should also be offered mitral valve reconstructive surgery where feasible.

Assessment for surgery

The surgeon has to have a three-dimensional understanding of the cause of the leak in the mitral valve. This is further assisted by intraoperative TOE, which is an absolute must during repair. This will give the final echocardiographic information and, along with the patient's history and intraoperative assessment, will aid in reaching the final conclusion as to whether the valve is repairable. The intraoperative TOE is further used to assess valve competency after completion of the repair and termination of cardiopulmonary bypass. MR of less than grade I is acceptable, whereas grade II or more should always lead to re-repair of the valve or, if it is irreparable, to replacement.

Methods of repair

Various methods are used in the treatment of mitral regurgitation, which can be broadly categorised on the basis of the leaflet involved, as table 2 shows.

Surgery should be comprehensive, paying attention to all the diseased components such as the annulus, the leaflets, the papillary muscles and the chordae tendineae. The goal should be to achieve the widest possible surface for coaptation without any prolapse. The curved coaptation closure line would then resemble a "smiling valve".⁴ Concomitant atrial fibrillation ablation and tricuspid valve reconstruction should also be performed where indicated.

The annuloplasty ring is an important additional component in each kind of repair. Its overall role would be to reduce the size of the annulus and decrease the tension on the

sutures while providing flexibility and mobility at the same time. It is to be noted, however, that to date no prospective randomised controlled trials have been done to support this point. Professor Carpentier had advocated the use of a rigid annuloplasty ring.⁴ Nevertheless, a better understanding of the three-dimensional motion of the mitral valve has heralded the development of the semirigid and flexible annuloplasty ring, which is preferred in degenerative mitral valve reconstruction. In ischaemic MR, owing to the restrictive mechanism, it may be preferable to use a rigid annuloplasty ring to maintain competency. The only exception to placement of an annuloplasty ring in mitral valve repair would be in cases of infective endocarditis to avoid excess foreign material.²² When an annuloplasty ring is used, three-month anticoagulation is preferable.

Leaflet sliding plasty is a technique designed by Carpentier and is usually used along with quadrangular resection in patients having a posterior leaflet height of > 1.5 cm. This is usually seen in degenerative conditions such as Barlow's disease, where there is excessive myxomatous leaflet tissue. Decreasing the excessive length with this technique or its modification helps to prevent systolic anterior motion and thus prevents obstruction to the LV outflow tract.²³

Among the various chordal repair techniques, chordal shortening is a procedure in which the papillary muscle is split and the chord is embedded inside the muscle. This procedure is not usually advocated, as the arterial supply to the papillary muscle is an end artery and such splitting of the papillary muscle may cause ischaemia. The amount of correction practicably possible is also limited and, even after the procedure, the diseased chords can still break or elongate. Chordal transfer, on the other hand, is a procedure in which an intact chord is excised from a normal leaflet and attached to a prolapsed leaflet. Another promising technique is neochordae repair, in which the chordae is reconstructed with an expandable polytetrafluoroethylene suture between the coapting edge of the leaflet and the associated papillary muscle. This suture has been found to have similar viscoelastic properties to chordae tendineae, and long-term

Figure 2 Carpentier's classification of mitral regurgitation into three functional types (I, II, III—see table 1). Arrows indicate "level of annulus".

Figure 3 Indications for mitral valve surgery.

studies have found it to be a reliable material in terms of durability and biological adaptability.²⁴ There are also no significant complications such as endocarditis, severe MR and mitral valve reoperation. Leaflet resection may also not be necessary. It is not a recommended procedure, however, for acute MR caused by a ruptured papillary muscle or avulsion of chordae tendineae.

The Alfieri stitch approximates the free edges of the leaflets at the site of regurgitation, which can be near the commissure or the central part; the central part creates a double orifice of the valve. Despite a reduction in mitral valve effective orifice area, no patient required reoperation for mitral valve stenosis in the experience of Alfieri *et al.*²⁵ In patients with Barlow's disease, this suture must plicate the leaflet redundancy to restore competence and prevent post-operative LV outflow obstruction caused by systolic anterior motion of the anterior leaflet.

Mitral stenosis

Reconstruction in mitral stenosis, where open surgical commissurotomy is done as an alternative to balloon

dilatation, should also be mentioned. Both have similar rates of restenosis. In addition, surgical commissurotomy should be considered before pulmonary hypertension (> 50 mm Hg) sets in, as it adds considerably to operative risk.²⁶

Atrial fibrillation and tricuspid regurgitation

Mitral valve surgery may also involve concomitant surgery for atrial fibrillation and tricuspid regurgitation. Cox maze III has been the ideal for atrial fibrillation surgery, but a modified form—a partial maze procedure—is also used, which adds only 10–20 min of additional cross-clamp time.²⁷ Similarly, when the tricuspid valve is dilated > 70 mm between the antero-septal and posterolateral commissures,²⁸ De Vega annuloplasty is carried out.

RECENT ADVANCES

We are now gradually moving towards minimally invasive mitral valve surgery. Percutaneous mitral valve procedures are under investigation as a novel method to treat mitral valve insufficiency with a catheter-based, closed-heart, non-

Table 2 Methods of treatment of mitral regurgitation

Pathological involvement	Treatment	Other treatment options	Notes
Posterior leaflet prolapse (usually P2)	Rectangular or quadrangular excision of prolapsed section		For mobilisation of the remaining leaflets, some secondary or tertiary chordae can also be resected
Anterior leaflet prolapse (usually A2)	Annuloplasty ring	Chordal shortening	
Bileaflet prolapse	Triangular resection	Chordal transfer	
	Annuloplasty ring	Neochordae placement	
	Posterior leaflet resection (when there is no significant anterior chordal abnormality)	Alfieri stitch	
	Annuloplasty ring		
No prolapse (annular dilatation)	Annuloplasty ring	Leaflet sliding plasty	Can be due to left ventricular dilatation

surgical approach.²⁹ Minimally invasive robotic surgery is being performed in an increasing number of institutions, especially in young patients. Alfieri's edge-to-edge technique is an attractive operation for minimally invasive surgery and the industry is also working towards developing a staple for this purpose.

The UK Heart Valve Registry Report 2001, published in March 2003, noted the ratio of aortic to mitral valve replacement to be 78:22. The proportion was 55 versus 45 for aortic and mitral replacements in 1986—that is, a ratio of 1.2 to 1. This change to a lower proportion of mitral valves being replaced may be due not only to a reduction in chronic rheumatic valvular disease but also an increase in the number of repairs. Interestingly, the Society of Thoracic Surgeons' Spring 2005 report shows the number of mitral valves repaired (3712) exceeding the number replaced (3579) for the first time in 2004, compared with the previous 10 years. This is indeed an encouraging trend.

CONCLUSION

More effort still needs to go into ensuring that patients undergo timely mitral valve repair. Mitral valve repair is technically more demanding and possibly requires a longer bypass time. Nevertheless, there are clear benefits to repair compared with replacement. LV function is improved due to preservation of the annulus–chordae–papillary complex. Similarly, multivariate analysis has shown less risk of thromboembolism and anticoagulation-related bleeding.³⁰ Techniques of repair are improving and surgical confidence is being built up through experience and increasingly by advanced technology delineating accurately the underlying mitral pathology. The ultimate goal is for the committed surgeon to progress in mitral valve repair where feasible, which will in turn show the quality of service that can be provided. At the same time, it falls on the cardiologist to advocate the feasibility of repair not only for patients with severe symptomatic MR and depressed LV function but also for asymptomatic patients with preserved LV function at the other end, especially when the end systolic diameter is approaching 45 mm. Promptly directing patients towards centres where mitral valves are repaired consistently will produce the best possible outcome.

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