Contemporary techniques for mitral valve repair—the Mayo Clinic experience

Hartzell Vernon Schaff¹ · Anita Nguyen¹

Received: 30 November 2018 / Revised: 22 January 2019 / Accepted: 25 January 2019 / Published online: 26 March 2019
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Abstract

Mitral valve repair for patients with degenerative or functional mitral valve regurgitation improves symptoms and prognosis, and several techniques have been described. Important principles in operation are simplicity, reproducibility, and durability of repair. At Mayo Clinic, we have operated on more than 6000 patients with degenerative mitral valve disease and valve prolapse, and this review details our approach to mitral valve repair, including robotic and minimally invasive techniques. Most patients with isolated leaflet prolapse can be managed with leaflet plication or triangular resection, and chordal replacement is reserved for repair of anterior leaflet prolapse. Posterior annuloplasty with a standard-sized flexible band is used to reduce annular circumference and improve leaflet coaptation. With these methods, early risk of mortality for mitral valve repair is low in the current era (< 1%), and rate of recurrent valve leakage is 1.5 per 100 patient-years during the first year post-repair and 0.9 per 100 patient-years thereafter. This paper also briefly summarizes important considerations for patients with mitral valve regurgitation and severe calcification, perforations due to endocarditis, and rheumatic heart disease.

Keywords Annuloplasty · Mitral valve repair · Outcomes

Introduction

Mitral valve anatomy is commonly described in regions of the valve leaflets. The posterior leaflet is divided into three segments, as viewed by the surgeon through a left atriotomy—P1 (lateral or anterior scallop), P2 (middle scallop), and P3 (medial or posterior scallop). The anterior leaflet has three corresponding segments—A1 (lateral or anterior portion), A2 (middle portion), and A3 (medial or posterior portion). The anterolateral and the posteromedial papillary muscles each have chordae tendineae that connect to both anterior and posterior leaflets.

Regurgitation of the mitral valve may be classified according to Carpentier's system. In type I mitral valve regurgitation, the leaflet motion is normal. Causes of type I regurgitation include annular dilatation or leaflet perforation. Leaflet prolapse is characteristic of type II mitral valve regurgitation, and is caused by chordal rupture or elongation, papillary muscle rupture, or papillary muscle elongation. Type III mitral valve

regurgitation is due to restricted leaflet motion during diastole (type IIIa) or systole (type IIIb) [1].

A simpler classification is to consider degenerative mitral valve regurgitation (mitral valve leakage due to degenerative disease with prolapse) versus functional mitral valve regurgitation (due to tethering of the papillary muscles and chordal attachments resulting in central valvular regurgitation). At Mayo Clinic, we have operated on more than 6000 patients with degenerative mitral valve disease and valve prolapse, and this paper summarizes our approaches to mitral valve repair that have evolved over this 35-year experience. The review also includes newer approaches to mitral valve repair, including robotic and minimally invasive techniques, as well as brief discussion of techniques for less common causes of mitral regurgitation such as valve calcification, perforations due to endocarditis, and rheumatic heart disease.

Repair of mitral leaflet prolapse

Posterior leaflet

Indications for operation are covered in guideline articles from the American College of Cardiologists and the American

✉ Hartzell Vernon Schaff
schaff@mayo.edu

¹ Department of Cardiovascular Surgery, Mayo Clinic, 200 1st Street SW, Rochester, MN 55905, USA

Heart Association [2]. Mitral valve regurgitation caused by flail segments almost always results in volumetrically severe mitral valve regurgitation [3]. Prolapse of mitral valve leaflets may be due to ruptured chordae tendineae or elongated chordae. In our experience, the most common site of prolapse is the middle (P2) scallop of the posterior leaflet, and this is the location of prolapse in approximately 60% of patients [4]. For these defects, we prefer repair of the prolapse using triangular resection of the unsupported leaflet portion or leaflet plication [5]. This technique can be applied to almost all patients whose chordae to the posterior leaflet have ruptured [6]. Some surgeons advocate use of artificial chordae for the posterior leaflet [7, 8], but we believe this is unnecessary for most patients with isolated posterior leaflet prolapse and has no demonstrable benefits compared to plication or limited resection.

To perform triangular leaflet resection, the surgeon first identifies the intact chordae on either side of and adjacent to the prolapsing segment (Fig. 1). The leaflet resection begins on the free edge, and the two lines of excision join just above the annulus (Fig. 2). The edges of the leaflet are then repaired in two layers using 4–0 polypropylene suture (Fig. 3). The shortened reconstructed free edge of the leaflet assumes a position at or below the plane of the valve. The main difference between this method and quadrangular resection is that there is no potential for unnecessary tension from a gap created by the excised leaflet near the annulus. Further, reinforcing pledgeted sutures at the base of the leaflet resection is not necessary with triangular resection, and there is no need for the “sliding leaflet technique” [9].

In patients with a small unsupported segment of the posterior leaflet, we sometimes use simple plication and imbrication of the segment with a figure-of-eight 4–0 polypropylene suture. Leaflet plication was originally described by McGoon, who should be credited with performing the first repair of ruptured chordae tendineae [5, 10]. Although many other

Fig. 1 Prolapse of the posterior mitral valve leaflet. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

Fig. 2 Triangular resection of the prolapsed segment of the posterior mitral valve leaflet. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

techniques for posterior leaflet repair have been described [11–13], posterior leaflet repair by triangular excision or plication is simple and expeditious. Risks of failure of repair due to suture dehiscence are small, and we have not observed this complication in our experience.

Anterior leaflet

Some clinicians may consider prolapse of the anterior leaflet of the mitral valve to be more difficult to repair than posterior leaflet prolapse. At Mayo Clinic, we do not resect the anterior

Fig. 3 Mitral valve after triangular leaflet resection. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

leaflet during mitral valve repair, but there are some groups who use partial leaflet resection for repair of anterior leaflet prolapse [14]. The rationale behind this is that there is less redundancy of anterior leaflet tissue compared to the posterior leaflet of the mitral valve. An important consideration is whether the anterior leaflet prolapse is segmental as seen with chordal rupture (Fig. 4) or elongated or diffuse producing multiple regurgitant jets. We use chordal replacement with 4-0 polytetrafluoroethylene (PTFE) suture for prolapsing anterior segments [7, 15]. The PTFE chord is inserted as a mattress suture with a small felt pledget. Both arms of the suture exit the fibrous tip of the papillary muscle but are not tied at the level of the papillary muscle. Each suture is then passed twice through the unsupported free edge of the anterior leaflet. Passing the suture twice gives some resistance and facilitates tying the suture. It is important not to overcorrect by approximating the leaflet edge too close to the papillary muscle as this restricts leaflet mobility and closure. Although some clinicians use premeasured chordal loops [16], this modification adds complexity and cost, and has not been necessary in our experience.

When the prolapsing segment of the anterior leaflet is near the commissure, the simplest repair is plication of the anterior and posterior leaflet with one or two figure-of-eight 4-0 polypropylene sutures. This method almost always eliminates valve prolapse and only minimally reduces the mitral valve orifice area. In selected patients, we have used the Alfieri suture, which joins the anterior and posterior leaflets close to the middle of the valve creating a double orifice valve [17]. This technique is particularly useful if there is residual prolapse of the anterior leaflet after completion of mitral valve repair and annuloplasty.

In patients with diffuse anterior leaflet prolapse, we begin repair with posterior annuloplasty as described below. In some patients, annuloplasty alone will correct diffuse overshoot of the anterior leaflet without the need for direct leaflet repair.

Fig. 4 Prolapse of the anterior leaflet of the mitral valve. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

Bileaflet prolapse

Careful inspection of the leaflets is crucial to determine whether there are ruptured chordae or segmentally elongated chordae. Rupture of chordae to both leaflets is uncommon, but when there are ruptured chordae to one leaflet and diffuse overshoot of the other leaflet, it is necessary to repair the unsupported segment with one of the techniques described above. In patients with bileaflet prolapse that appears diffuse without ruptured chordae (as often seen in Barlow's disease, Fig. 5), we begin repair with posterior annuloplasty alone. Mitral annuloplasty with a posterior band or a complete ring will reduce the annular circumference and the anterior-posterior dimension of the orifice, thereby increasing coaptation area on the ventricular side of the valve annulus. If there is residual prolapse after annuloplasty, direct repair of the leaflet can be performed. In most instances, however, simple annuloplasty is sufficient [13, 18].

Mitral valve annuloplasty

Mitral valve annuloplasty is an important component of most mitral valve repairs. Annuloplasty reinforces the leaflet repair and narrows the valve orifice, thereby improving coaptation of the anterior and posterior leaflets. There are many techniques for annular reduction, including use of simple sutures [19–21], prosthetic rings (rigid, flexible, and semi-rigid) [1, 22], and posterior annuloplasty bands [23, 24]. Simple suture plication is rarely used in adult patients, but may be applicable to some cases of congenital mitral valve disease where localized areas of the annulus are reduced. Furthermore, suture plication may be useful for patients with severe calcification of the valve annulus, which prevents reduction of the entire posterior aspect of the valve.

Fig. 5 Prolapse of both anterior and posterior mitral valve leaflets. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

At Mayo Clinic, we favor annular reduction using a flexible prosthetic posterior annuloplasty band (Fig. 6) [23, 24]. This technique has several advantages. First, dilatation of the mitral valve annulus occurs primarily in the posterior aspect of the valve. Although studies show that there is some enlargement of the anterior aspect of the mitral valve in patients with functional mitral valve regurgitation [25], this is relatively small and unimportant in most patients with degenerative mitral valve pathology [26]. Thus, the portion of the annulus that needs to be reduced extends posteriorly from the right to the left fibrous trigones. Limiting the annuloplasty to the posterior aspect of the annulus facilitates the procedure.

There is no standardized method for sizing mitral valve annuloplasty rings or bands, as practice varies among manufacturers and surgeons. At Mayo Clinic, we use a standardized flexible annuloplasty band that is approximately 6.3 cm in length. Pathologic studies have demonstrated that the normal circumference of the mitral valve is approximately 10 cm, and the ratio of the length of the anterior (fibrous) portion to the posterior (muscular) annulus is 1:2. Thus, a posterior band of approximately 6 to 6.6 cm is adequate to reduce the posterior annulus to nearly normal dimensions. In practice, this length is usually smaller than the measured band size after the mattress sutures have been secured. In most patients, we use 7 to 9 equally spaced sutures to attach the band. In our initial experience, we constructed the flexible band from a complete ring [23], but we now use a commercially available annuloplasty band without sizer or handle in order to minimize cost. Although many surgeons advocate measurement of various mitral valve dimensions prior to selection of an annuloplasty ring, we favor the unmeasured standard-sized posterior band as it simplifies the operation and is highly reproducible. Use of an incomplete annuloplasty band simplifies the repair and may shorten ischemic and operative times [24].

Potential disadvantages of using a standardized band are that it may be too large for a small patient leading to regurgitation or

too small for a large patient creating functional stenosis. However, in a study of hemodynamic effects of standard length posterior annuloplasty, we found no important difference in both mitral valve gradient and degree of residual regurgitation over a wide range of sizes of adult patients (Fig. 7) [24].

Following mitral valve repair for degenerative disease, recurrence of regurgitation is low. In a review of more than 1200 patients who underwent mitral valve repair at Mayo Clinic, Suri et al. reported a 15-year incidence of recurrent mitral valve regurgitation of 13.3%, and the 15-year risk of reoperation was 6.9% [4]. In some patients, the reason for recurrence of regurgitation and need for subsequent valve re-repair or replacement is additional leaflet pathology, e.g., a newly ruptured chord, and in others, there is failure of initial repair. Interestingly, Suri and coauthors noted that rates of mitral valve recurrence decreased markedly following the first year after surgical repair. It is important to recognize that recurrence of mitral valve regurgitation was associated with late death.

Minimally invasive techniques

Minimally invasive mitral valve repair refers to operation performed via incisions other than full sternotomy. These approaches include partial sternotomy, mini-thoracotomy, robotic surgery, and others. Minimally invasive approaches are perceived as less traumatic by patients and some referring physicians, a potentially important consideration for patients who need repair of severe mitral valve regurgitation but have few or no limiting symptoms preoperatively. The potential disadvantages of this approach are the time required for the procedure and the possible increased risk of stroke and aortic dissection if retrograde perfusion is used for cardiopulmonary bypass [27, 28].

Fig. 6 Annular reduction using a flexible prosthetic posterior annuloplasty band. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved). Annuloplasty band is sewn into the mitral valve in (a), and in place in (b)

Fig. 7 Panel **a** shows mitral valve regurgitation at discharge after mitral valve repair with standard-sized annuloplasty. Panel **b** shows mean ($\pm$ SD) mitral valve gradients after mitral valve repair [24]

Port access mitral valve repair

In the majority of cases, minimally invasive mitral surgery is performed through a right anterolateral mini-thoracotomy, either under direct vision or endoscopically via port access. When performed by experienced surgeons, minimally invasive mitral valve repair is safe and has satisfactory early outcomes as regards functional results of mitral valve repair and mortality, but time required on cardiopulmonary bypass and time of aortic cross clamping are increased more than threefold [29].

Robotic-assisted mitral valve repair

Mitral valve repair can also be performed with a robotic approach, and this is appropriate for both degenerative and functional mitral valve disease [30, 31]. Advantages of the robotic approach compared to other minimally invasive techniques include better visualization and ability to perform precise movements through the robotic console. A robotic mitral valve repair is usually performed through an incision in the right chest, and thus, patients with intrathoracic pathology may not be suitable candidates for robotic mitral valve operation.

To perform robotic mitral valve repair, the groin and right neck are cannulated for bypass. The robotic instruments are inserted into the right chest through a mini-thoracotomy. The ascending aorta is cannulated and the heart is arrested with cold blood cardioplegia. The left atrium is incised and the mitral valve is assessed visually. Mitral valve repair techniques using the robotic approach are similar to the ones described above. For patients with posterior leaflet disease, we perform a standard triangular resection with two-layer polypropylene reconstruction (Fig. 8). For those with anterior leaflet prolapse, polytetrafluoroethylene (Gore-Tex; W. L. Gore & Associates, Inc., Flagstaff, AZ) with neochoord resuspension is utilized. All repairs are protected with a posterior annuloplasty band.

Mitral valve repair—special circumstances

Endocarditis and leaflet perforation

Endocarditis can cause severe mitral valve regurgitation due to leaflet erosion, chordal rupture, or leaflet perforation. In many patients, valve replacement is the most appropriate

Fig. 8 Triangular resection of the posterior mitral valve leaflet using the robotic approach [30]. (Used with permission of Suri RM, Dearani JA, Mihaljevic T, et al. Mitral valve repair using robotic technology: safe, effective, and durable. *J Thorac Cardiovasc Surg.* 2016;151(6):1450–1454. Copyright The American Association for Thoracic Surgery)

operation. However, in patients whose grossly infected tissue can be debrided with preservation of basic structural integrity of the mitral valve, valvuloplasty may be possible, although patch augmentation is frequently necessary. A durable repair is more likely to be achieved in patients with healed endocarditis, although successful mitral valve repair in patients with acute infection is possible [32, 33]. In our experience of surgically managing patients with mitral valve endocarditis, both early and late outcomes were superior in those who underwent valve repair rather than replacement [34].

A jet lesion from the aortic valve in patients with aortic valve endocarditis may cause perforation of the anterior mitral valve leaflet. This defect can easily be repaired with an autologous pericardial patch (Fig. 9) [35], and often the repair can be performed through the aortotomy at the time of aortic valve replacement. In approximately 60% of patients, patch repair of the anterior leaflet is supplemented by mitral valve annuloplasty [36].

Fig. 9 Autologous pericardial patch repair of the anterior mitral valve leaflet. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved)

Leaflet and annular calcification

There are very few contraindications to valve repair for patients with degenerative mitral valve regurgitation, but presence of calcium in the annulus and leaflets reduces the likelihood of a successful repair. Annuloplasty cannot be performed in patients with extensive annular calcification. In some instances, flail leaflets can be repaired, and additional annuloplasty may not be necessary if there is little annular dilatation. In other patients, the calcification does not extend around the entire annulus, and annular circumference can be reduced in a localized area to improve coaptation. If there is extensive calcification of the leaflets associated with severe mitral valve regurgitation, the best option is likely mitral valve replacement. Patients with severe calcification of the mitral annulus are often elderly, and bioprostheses can be used. Other causes of extensive calcification include dialysis-dependent chronic renal failure and radiation-induced heart disease. These patients will often have severe mitral valve stenosis, and mitral valve replacement is a better option in these instances.

Mitral valve regurgitation due to rheumatic heart disease

Mitral valve regurgitation due to rheumatic heart disease is relatively uncommon in North America, and in our experience, most patients with rheumatic mitral valve disease have some degree of stenosis associated with thickening or calcification of the leaflets which reduces chance for successful repair. However, in developing countries, rheumatic heart disease is still prevalent, and in young patients often causes mitral valve regurgitation due to redundant leaflets and chordal elongation. In these patients, mitral valve repair is a good option [37]. Use of artificial chordae during repair of pure rheumatic mitral regurgitation may improve results compared to previous techniques of chordal transposition. In older patients with leaflet retraction, patch augmentation of restricted leaflets can be utilized [38, 39].

Summary

The techniques described for valve repair are simple, reproducible, and have durable results in patients with mitral valve regurgitation due to degenerative disease. Recurrent mitral regurgitation after valve repair is a serious problem and is

associated with progressive left ventricular enlargement and late death, but risks of recurrence following surgical repair are low, especially in patients who have isolated posterior leaflet prolapse preoperatively and those in whom annuloplasty is performed (Fig. 10) [4]. Indeed, for patients having repair of posterior leaflet prolapse, the risk of developing recurrent

Fig. 10 Recurrence of mitral valve regurgitation following mitral valve repair. Panel **a** shows cumulative incidence of mitral valve regurgitation stratified by presence of mild intraoperative regurgitation. Panel **b** describes incidence of recurrence by location of prolapse. Panel **c** shows cumulative incidence of recurrent mitral valve regurgitation in patients with and without annuloplasty ring [4]. (Used with permission of Suri RM, Clavel MA, Schaff HV, et al. Effect of recurrent mitral regurgitation following degenerative mitral valve repair: long-term analysis of competing outcomes. *J Am Coll Cardiol*. 2016;67(5):488–498. Copyright The American College of Cardiology Foundation)

regurgitation severe enough to warrant reoperation is similar to the risk of reoperation for patients who undergo mitral valve replacement with a mechanical prosthesis [40].

Funding This work was supported by the Paul and Ruby Tsai Family.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement Not applicable.

Informed consent Not applicable.

Human and animal rights Not applicable.

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