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The 10 Commandments for Mitral Valve Repair

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Introduction

Mitral valve repair is most applicable to patients with mitral regurgitation caused by degenerative disease (i.e., mitral valve prolapse). In such patients, valve repair provides superior outcomes to valve replacement. Advantages of mitral valve repair over replacement include reduced early and late mortality, better preservation of left ventricular function, and greater freedoms from thromboembolism, endocarditis, and anticoagulant-related hemorrhage.[1–4] Since Carpentier's development of a suite of surgical techniques for mitral valve repair, surgeons have continued to innovate, adding to the options available to restore mitral valve function.[1–5] As a consequence, surgeons now have a wide variety of options when addressing the prolapsing mitral valve and repair should be feasible in more than 90% of cases.[1–5] Regardless of the repair techniques chosen, the surgeon must recognize and adhere to specific principles in order to conduct a safe operation and achieve a successful and durable repair. These principles are the 10 Commandments for Mitral Valve Repair.

1. Study the Intraoperative, Prerepair Echocardiogram

In the early days of mitral valve repair, detailed valve inspection by the surgeon preceded valve repair and informed the key decision points concerning the surgical strategy for addressing the valve. Surgical valve inspection remains an integral component of the procedure, but careful study of the intraoperative, prerepair transesophageal echocardiogram is a critical first step in planning. The echocardiogram provides the information that enables the surgeon to decide upon repair techniques. The surgeon should take the time to examine the echocardiogram with the echocardiographer. When considering the echocardiogram, the surgeon and echocardiographer have 4 key tasks: (1) identify the precise mechanism(s) of mitral regurgitation, (2) determine the risk of systolic anterior motion (SAM), (3) note the left ventricular function, and (4) examine the tricuspid valve.

Of course, the most important question to answer is, "What is the mechanism of mitral regurgitation?" Two- and 3-dimensional echocardiography will almost always reveal the precise cause of mitral regurgitation. Without color flow, the site of prolapse/flail should be evident. The addition of color flow enables visualization of the jet and jet direction provides an important clue to confirm the site of prolapse. An anterior jet indicates posterior prolapse and a posterior jet indicates anterior prolapse. A central jet can indicate balanced bileaflet prolapse, annular dilatation, or functional MR caused by left ventricular dysfunction/dilatation. Although uncommon, more than 1 site of prolapse does occur occasionally. Therefore, complete interrogation of the valve is necessary.

Once the site of prolapse is identified, the risk of SAM must be assessed. Put simply, postrepair SAM results from excess leaflet tissue. While the echocardiographer can perform a variety of measurements to indicate the risk of postrepair SAM, from the surgeon's perspective, it is most useful to classify the risk as low, intermediate, or high.[6] In those with intermediate or high risk, surgical planning should be adjusted accordingly in order to prevent the development of SAM.

The surgeon should also take note of ventricular function and the status of the tricuspid valve. Patients with a dilated left ventricle, particularly when accompanied by reduced left ventricular function, will often require inotropic support to separate from cardiopulmonary bypass. Tricuspid valve repair should be considered in patients with tricuspid regurgitation on preoperative echocardiogram and/or tricuspid annular dilatation.[7]

2. Choose the Safest Chest Wall Approach

There is great interest in less invasive mitral valve surgery on the part of both surgeons and patients. While a full sternotomy has long been the standard approach, less invasive options include partial sternotomy (upper or lower), right minithoracotomy, and robotic surgery (Fig. 1). Various groups have achieved excellent results with each of these incisions; however, no approach has been proven to be generally superior to the others.[8–12] The surgeon should fit the procedure to both the patient's anatomy/physiology and the surgeon's skill/comfort level. Surgeons may opt to "push the envelope" and tackle a complex valve with a less invasive approach. This is a mistake and can

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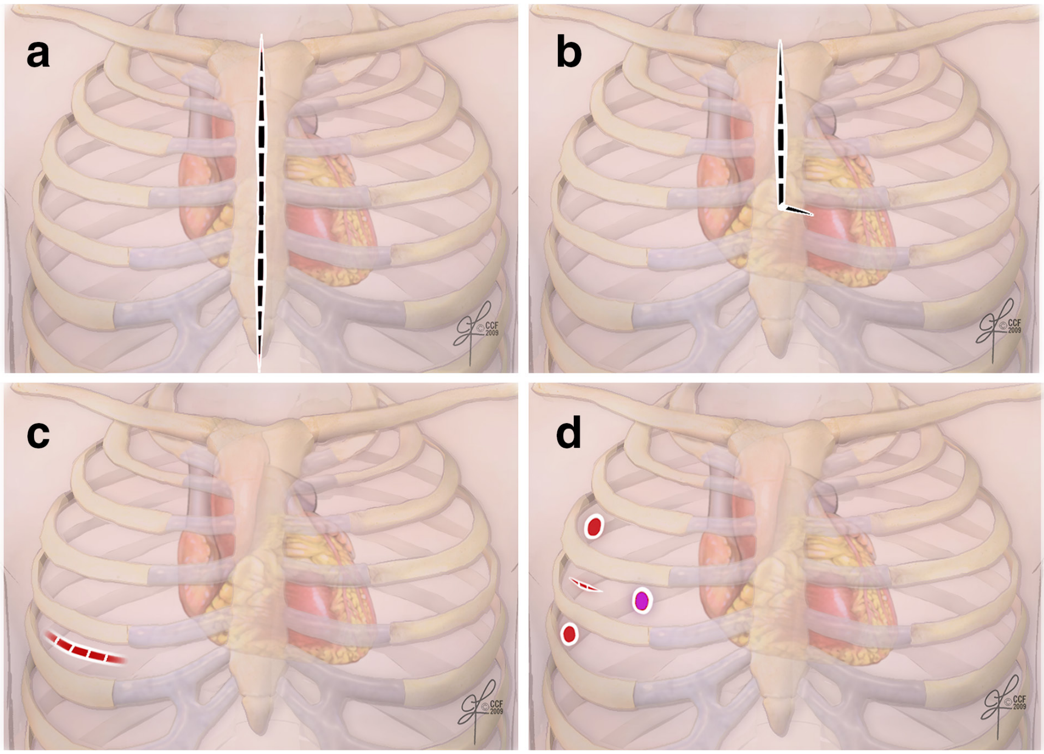

Fig. 1. Incisions for mitral valve surgery. (a) Full sternotomy, (b) partial upper sternotomy, (c) right minithoracotomy, (d) robotically assisted approach.

result in extended cross-clamp times, limb ischemia (in the case of femoral perfusion), and adverse outcomes.

Patients often prefer non-sternotomy approaches, and patient preference is, of course, an important consideration. But safety must come first. We recommend rigorous application of a screening algorithm in order to identify patients with isolated degenerative mitral valve disease who are best suited for robotic/right thoracic mitral valve operations (Fig. 2).[8] Screening begins with transthoracic echocardiography. If the patient has significant left or right ventricular dysfunction, we favor a sternotomy as that approach is associated with a shorter period of myocardial ischemia and enables optimal cardioplegia delivery (i.e., both antegrade and retrograde cardioplegia and topical myocardial cooling). Aortic regurgitation that is more than mild jeopardizes myocardial protection with antegrade cardioplegia in right thoracic approaches, and this finding should also steer the surgeon toward a sternotomy-based approach. Finally, the presence of severe mitral annular calcification indicates that the operation will be complex and a sternotomy is best in this situation.

Preoperative, contrast-enhanced computed tomographic (CT) scanning of the chest, abdomen, and pelvis is essential before employing a right thoracic approach with femoral perfusion. We have identified important vascular abnormalities, including a discontinuous inferior vena cava, an unreported inferior vena cava filter, and a type B dissection on preoperative CT scans. Patients with these findings underwent uneventful sternotomies. The presence of aortoiliac atherosclerosis, particularly soft plaque, precludes safe femoral perfusion as it is associated with an increased risk of stroke. Surgeons should recognize that the absence of coronary artery disease does not guarantee a "clean" aortoiliac tree. All patients should have CT scanning before the surgeon employs femoral perfusion. Finally, femoral arteries less than 7 mm in diameter limit arterial inflow and increase the risk of femoral artery damage with cannulation and perfusion. Devastating limb ischemia is a rare complication that can be prevented by avoiding perfusion via small femoral arteries.

3. Obtain Good Valve Exposure

To secure a good repair, the surgeon must be able to see the valve. This begins with choice of the chest wall incision. A robotic approach nearly always enables excellent visualization of the valve. Absent the capability to do robotic surgery, the patient's body habitus should be considered when deciding on the incision. Very obese patients and those with a severe pectus excavatum should have a standard sternotomy in order to optimize exposure. After performing the sternotomy, the pericardium is opened slightly to the right of the midline. Pericardial stay sutures should be placed only on the right side in order to allow the heart to rotate to the left. Placing a snare around the

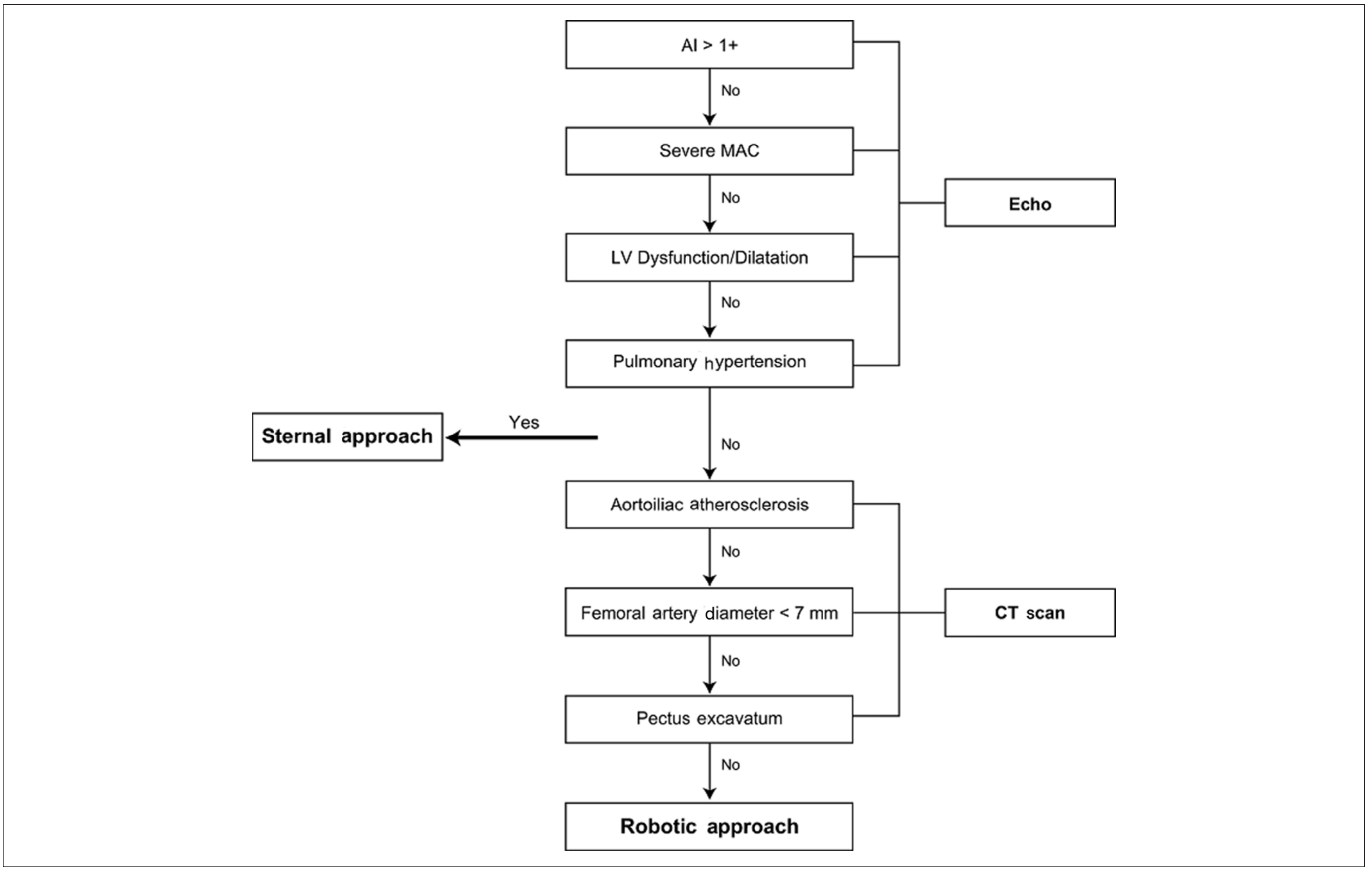

Fig. 2. Algorithm to determine candidacy for right chest/robotic approach to the mitral valve. CT, computed tomography; LV, left ventricular; MAC, mitral annular calcification.

inferior vena cava and distracting it under tension toward the patient's feet further enhances exposure.

For valve exposure, we favor a left atriotomy in most patients. Development of Waterston's groove can enhance visualization by bringing the surgeon closer to the anterior leaflet of the mitral valve. Use of a self-retaining retractor with 3 blades optimizes exposure. We generally spend a minute or two ensuring that the retractor blades are in the best possible positions to see the valve. Occasionally the surgeon may need to reposition the retractor blades during the repair.

If the left atrium is small or the patient very "deep," the surgeon should consider a trans-septal approach to the mitral valve. Carrying this incision onto the dome of the left atrium enhances exposure but invariably transects the artery to the sinus node, which increases the likelihood of postoperative rhythm disturbances and the need for a permanent pacemaker. Still, it is a worthwhile trade-off in order to optimize valve exposure in the challenging patient.

4. Place Annuloplasty Sutures First

In nonrobotic approaches, once the left atrium or interatrial septum has been incised and exposure optimized, we place the annuloplasty sutures. Placing the annuloplasty sutures first enhances exposure and enables a more complete valve inspection. We place the first annuloplasty suture wherever it is easiest; most often this is in the region of P2. Traction on this suture enables placement of the next suture, a maneuver that can be repeated sequentially until all of the annuloplasty sutures are in place. If exposure is particularly challenging, affixing annuloplasty sutures to the drapes under tension elevates the valve and brings it closer to the surgeon.

Annuloplasty sutures should extend from trigone to trigone when a band (vs. a ring) is employed. The trigones are generally 1 stitch beyond the commissure, and they are visible as "dimples" and appreciated by the surgeon as firm tissue as the needle passes through them. As sutures are placed in the annulus, the needle tips should be directed toward the valve/ventricle. This is particularly important as the surgeon approaches the region of the annulus near the orifice of the left atrial appendage and the left fibrous trigone; the circumflex coronary artery often courses in this area and, if a suture strays from the annulus, it may damage or kink the circumflex.

5. Valve Inspection

In general, the initial repair strategy will have been determined by study of the preoperative echocardiogram. Valve inspection is employed to confirm and augment echocardiographic findings. Once valve exposure has been optimized and the annuloplasty sutures are in place, the surgeon can perform a detailed valve inspection. This should be undertaken with the echocardiogram findings in mind. It is often helpful to begin with a saline test. The surgeon insufflates the left ventricle with saline and identifies the region(s) of leak. In addition to identifying areas of prolapse and ruptured chordae, the surgeon should note indentations/clefts and areas of leaflet restriction. Clefts and indentations may leak after repair, particularly when the surgeon performs a resection. Leaflet restriction is common in the P1 region. Apparent leaks in this area can be corrected by severing the offending, restricting chordae. The surgeon should also assess posterior leaflet height; a tall posterior leaflet is associated with an increased risk of SAM, necessitating preventive measures.

6. Choose Repair Techniques That Work for You

Mitral surgeons enjoy debating the relative merits of different repair techniques. Some surgeons always perform resection, while others "respect" the valve and routinely create artificial chordae.[13,14] Both techniques work well. Therefore, the surgeon should choose the technique that works best for him or her.[15]

Isolated posterior leaflet prolapse can be repaired equally effectively by leaflet resection or by creation of artificial chordae. For areas of limited prolapse, a triangular resection is simple and quick. Extensive, multisegment posterior prolapse is most amenable to creation of artificial chordae (Video 1). While some surgeons advocate a combination of both leaflet resection and creation of artificial chordae, we rarely find this to be necessary.

Anterior leaflet prolapse should be treated by creation of artificial chordae. Anterior leaflet resection is almost never a good choice. While chordal transfer is effective, creation of artificial chordae is simpler and quicker.

The primary challenge with artificial chordae is the judgment of chordal length. Surgeons have devised a variety of techniques for accomplishing this task.[13] The loop technique enables surgeons to employ premeasured chordae of a length that corresponds to that of native, normal chordae (Fig. 3a). If the surgeon chooses to construct free-hand chordae, we recommend adjusting the final length after the annuloplasty has been secured (Fig. 3b). In general, chordae to the posterior leaflet will be shorter than those to the anterior leaflet. Once initial chordal length has been determined, the ventricle is insufflated with saline and the point of coaptation determined. Chordal length is then adjusted to ensure good leaflet coaptation.

7. Use a Prosthetic Annuloplasty

All repairs for degenerative disease should be accompanied by insertion of a prosthetic annuloplasty.[3] There is no place for suture or pericardial annuloplasties in mitral valve repair. In degenerative disease, surgeons have a choice of annuloplasty: ring vs. band, rigid vs. flexible (Fig. 4). In general, it does not

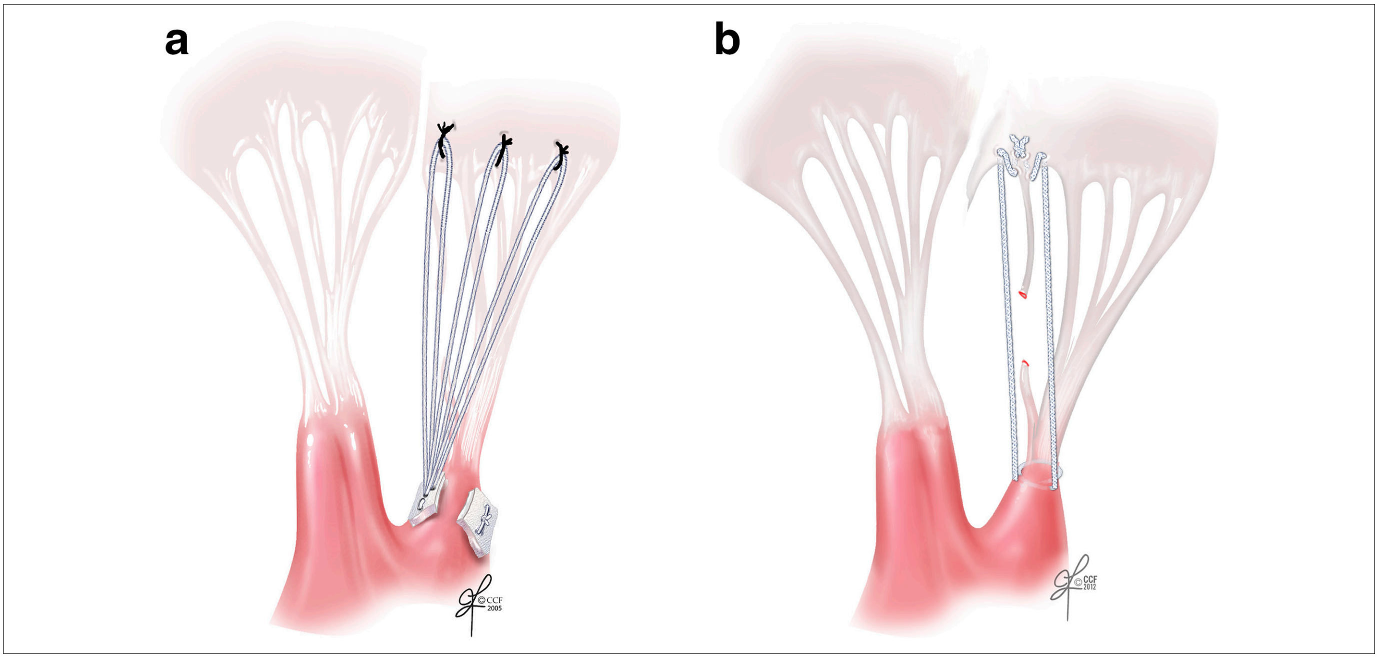

Fig. 3. (a) Loop technique for creation of artificial chordae. (b) Free-hand technique for creation of artificial chordae.

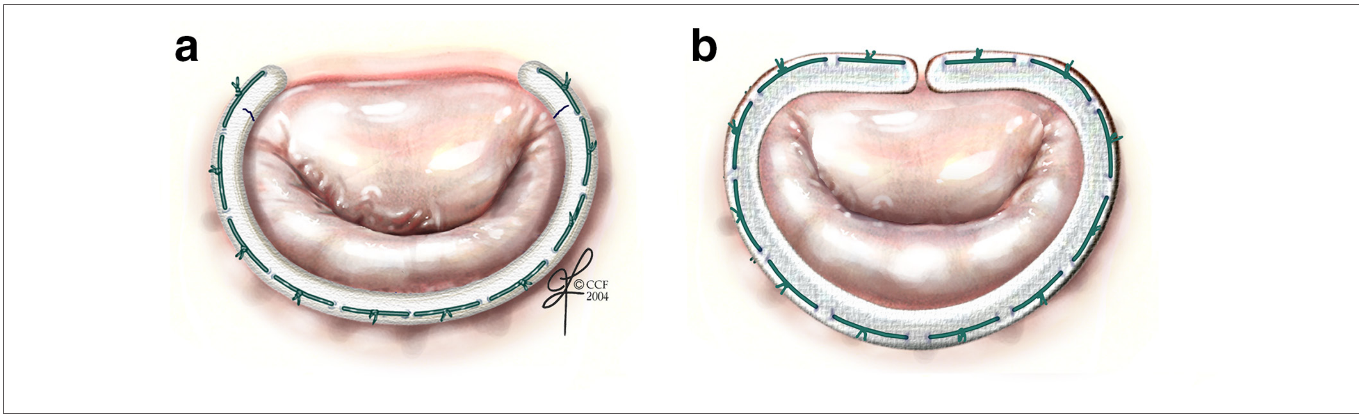

Fig. 4. Prosthetic annuloplasty (a) band and (b) ring.

matter which the surgeon chooses. In most cases, we favor a flexible band as this provides excellent results and facilitates robotic surgery. If the patient has a mixed lesion (e.g., prolapse in 1 region of the valve accompanied by areas of restriction attributable to left ventricular dysfunction/dilatation), a complete ring may be advisable as this provides a greater reduction in septal-lateral diameter.

Like annuloplasty type, annuloplasty sizing generates controversy among surgeons. Some groups favor a single annuloplasty size for all patients. We do not follow this dictum. That said, most patients with degenerative disease will be best served by a relatively large annuloplasty band or ring. Sizing according to the surface area of the anterior leaflet provides the best guidance for annuloplasty sizing.

8. Avoid SAM

The only way to completely avoid SAM is to refrain from performing mitral valve surgery (Fig. 5). That said, in most cases, the risk of SAM can be predicted, affording the surgeon the opportunity to choose repair techniques that will reduce the likelihood of this complication. Avoiding SAM begins with careful study of the preoperative echocardiogram. While the echocardiographer can provide a variety of measurements, the surgeon should examine the echocardiogram and look for 3 features: (1) excess leaflet tissue, (2) a septal bulge, and (3) a small, hyperdynamic ventricle. If any 2 of these features are present, the surgeon should take preemptive measures to avoid SAM.

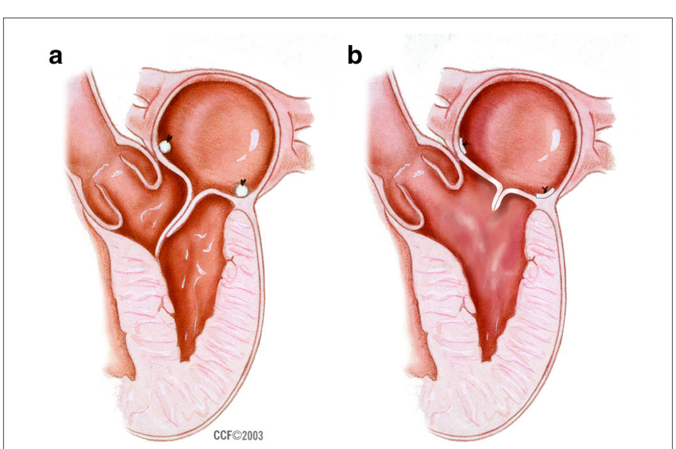

Fig. 5. (a) SAM with obstruction of left ventricular outflow tract. (b) No SAM with mitral leaflet coaptation distant from left ventricular outflow tract. SAM, systolic anterior motion.

Surgical maneuvers to prevent SAM center on efforts to move the point of coaptation posteriorly. Avoiding too small of an annuloplasty is important in this regard. Posterior leaflet height can be reduced by performing a posterior leaflet resection and sliding repair if the posterior leaflet is tall and posterior leaflet prolapse predominates. Alternatively, creation of posterior leaflet chordae that are very short will ensure that leaflet tissue does not move toward the left ventricular outflow tract during systole. While some surgeons employ an edge-to-edge repair (i.e., Alfieri stitch) to prevent or treat SAM, we rarely choose this technique as it invariably creates some element of mitral stenosis.

9. Wait for Recovery of Ventricular Function Before Assessing the Mitral Valve Repair

It is important to confirm that left ventricular function has returned to its baseline level before assessing the quality of the mitral valve repair. Left ventricular function is integral to mitral valve function. If ventricular function is sluggish, perhaps as a result of air transit down the right coronary artery, functional mitral regurgitation may ensue. This will present as a central or anteriorly directed jet of mitral regurgitation. It nearly always resolves with recovery of left ventricular function, which requires time, a high systemic blood pressure, and administration of inotropes in some cases.

Assessment of SAM also requires consideration of left ventricular function. If left ventricular function is diminished on initial weaning from cardiopulmonary bypass, SAM will not occur. However, as the left ventricle recovers and function improves, excess leaflet tissue may cause SAM that was not recognized initially.

We reduce the likelihood of these 2 occurrences by ensuring full ventricular recovery before final weaning from cardiopulmonary bypass. Once all air has cleared and transesophageal echocardiography confirms restoration of cardiac function, we separate from bypass but leave all cannulas in place. We then take several minutes to perform a full echocardiographic assessment of the mitral valve and the ventricles. When mitral valve function has been confirmed, we return to full cardiopulmonary bypass so that we can remove the antegrade cardioplegia catheter under controlled conditions. We then wean from bypass and decannulate in standard fashion.

10. Do Not Accept a Bad Repair

The surgeon should almost never accept a repair that ends with mitral regurgitation that is greater than mild (1+). In fact, even mild mitral regurgitation at the completion of the repair is associated with an increased risk of late repair failure.[16] If there is any residual mitral regurgitation on intraoperative transesophageal echocardiography, careful study of the echocardiogram is warranted. Evidence of a technical problem like suture deshiscence requires a second pump run for correction. Similarly, identification of a cleft/indentation in the posterior leaflet is easily addressed by simple suture closure in a second pump run. Eccentric jets of mitral regurgitation always mandate further work on the valve, as such jets indicate residual prolapse that must be corrected.

While a second pump run can be both challenging and troubling for the surgeon, it is the surgeon's responsibility to ensure that the patient leaves the operating room with a good mitral valve repair. A good long-term result begins with a good short-term result.

Conclusions

Mitral valve repair is possible in more than 90% of patients with degenerative mitral valve disease. The combination of clinical experience and faithful adherence to the principles outlined herein will enable surgeons to best serve their patients and meet this target.

Declaration of Conflicting Interests

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Supplemental Material

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