Minimally invasive mitral valve surgery (MIMVS) Evolution

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Abstract

To perform the ideal cardiac valve operation surgeons, need to operate in restricted spaces through tiny incisions, which require assisted vision and advanced instrumentation. Although this goal has not been achieved widely, MIMVS has continued to evolve toward videoassisted or video-directed operations. Moreover, new robotic methods offer endoscopic possibilities for mitral valve surgeons that heretofore were impossible. Via both videoassisted and direct vision, MIMVS now is within the reach of most cardiac surgeons. Yet the steep learning curve still can be an impediment to its more widespread adoption. Developments in minimally invasive mitral surgery began in the mid-1990s.

Keywords: Minimally invasive mitral valve surgery

Introduction

Full median sternotomy has been well established as a standard approach for all types of open heart surgery for many years. Although well established, the full sternotomy incision has been frequently criticized for its length, post operative pain and possible complications like wound infection and instability **(1)**.

Less invasive mitral valve operations offer certain advantages, such as reduce post operative discomfort and decrease postoperative recovery time

Indications of MV surgery

Classification of the Severity of Valve Disease in Adults

Stages of mitral stenosis

Stage	**Definition**	**Valve Anatomy**	**Valve Hemodynamics**	**Hemodynamic Consequences**	**Symptom**
A	At risk of MS	Mild valve doming during diastole	Normal transmitral flow velocity	None	None
B	Progressive MS	Rheumatic valve changes with commissural fusion and diastolic doming of the mitral valve leaflets Planimetered MVA ——— 1.5 cm2 (MVA ——— 1.0 cm2 with very severe MS)	Increased transmitral flow velocities MVA >1.5 cm2 Diastolic pressure half-time	Mild-to-moderate LA enlargement Normal pulmonary pressure at rest	None
C	Asymptomatic severe MS	Rheumatic valve changes with commissural	MVA ——— 1.5 cm2 (MVA - 1.0 cm2 with very severe MS)	Severe LA enlargement Elevated PASP >30 mm Hg	None

		fusion and diastolic doming of the mitral valve leaflets Planimetered MVA ——— 1.5 cm2	Diastolic pressure half-time 150 ms (Diastolic pressure half-time 220 ms with very severe MS)		
D	Symptomatic severe MS	S Rheumatic valve changes with commissural fusion and diastolic doming of the mitral valve leaflets Planimetered MVA ——— 1.5 cm2	MVA ———— 1.5 cm2 (MVA 1.0 cm2 with very severe MS) Diastolic pressure half-time 150 ms (Diastolic pressure half-time 220 ms with very severe MS)	Severe LA enlargement Elevated PASP >30 mm Hg	Decreased exercise tolerance Exertional dyspne

Table 1: Stages of mitral stenosis **(2)**

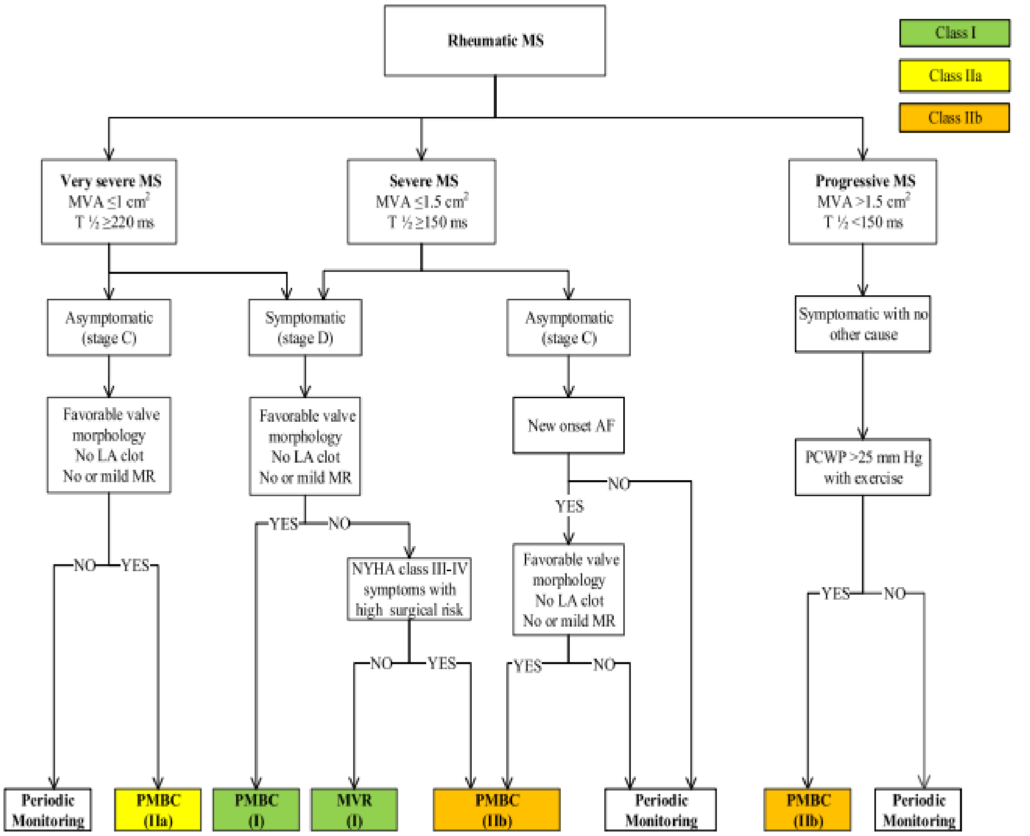

Figure 1: Rheumatic Mitral stenosis **(2)**

Stages of mitral regurgitation

	Definition 129 1dddd	**Valve Anatomy**	**12Valve Hemodynamics**	**29v Hemodynamic Consequences**	**Hemodynamic Consequences**
	At risk of MR	Mild mitral valve prolapse with normal coaptation Mild valve thickening and leaflet restriction	No MR jet or small central jet area	None	None

	Progressive MR	R Severe mitral valve prolapse with normal coaptation Rheumatic valve changes with leaflet restriction and loss of central coaptation Prior IE	Central jet MR 20%–40% LA or late systolic eccentric jet MR Vena contracta	Mild LA enlargement No LV enlargement Normal pulmonary0 pressure	None
	Asymptomatic severe MR	Severe mitral valve prolapse with loss of coaptation or flail leaflet Rheumatic valve changes with leaflet restriction and loss of central coaptation Prior IE Thickening of leaflets with	Central jet MR >40% LA or holosystolic eccentric jet MR Vena contracta 0.7 cm Regurgitant volume 60 mL Regurgitant fraction 50% ERO 0.40 cm2 Angiographic grade 3–4þ	Moderate or severe LA enlargement LV enlargement Pulmonary hypertension may be present at rest or with exercise C1: LVEF >60% and LVESD	None

	Symptomatic severe MR	Severe mitral valve prolapse with loss of coaptation or flail leaflet Rheumatic valve changes with leaflet restriction and loss of central coaptation Prior IE Thickening of leaflets with radiation heart disease	Central jet MR >40% LA or holosystolic eccentric jet MR Vena contracta 0.7 cm Regurgitant volume 60 mL Regurgitant fraction 50% ERO 0.40 cm2 Angiographic grade 3–4þ	Moderate or severe LA enlargement LV enlargement Pulmonary hypertension present	Decreased exercise tolerance Exertional dyspnea

Table 2: Stages of mitral regurgitation **(2)**

Types of Surgery

Three different MV operations are currently used for correction of MVD: 1) MV repair; 2) MV replacement with preservation of part or all of the mitral apparatus; and 3) MV replacement with removal of the mitral apparatus. Each procedure has its advantages and disadvantages, and therefore, the indications for each procedure are somewhat different.

Indications of surgery for Mitral Valve regurgitation

Class I

1. MV surgery is recommended for the symptomatic patient with acute severe MR (Level B Evidence).

2. MV surgery is beneficial for patients with chronic severe MR and NYHA functional class II, III, or IV symptoms in the absence of severe LV dysfunction (severe LV

dysfunction is defined as ejection fraction less than 0.30) and/or end-systolic dimension greater than 55 mm (Level B Evidence).

3. MV surgery is beneficial for asymptomatic patients with chronic severe MR and mild to moderate LV dysfunction, ejection fraction 0.30 to 0.60, and/or end-systolic dimension greater than or equal to 40 mm (Level B Evidence).

4. MV repair is recommended over MV replacement in the majority of patients with severe chronic MR who require surgery, and patients should be referred to surgical centers experienced in MV repair (Level C Evidence).

Class IIa

1. MV repair is reasonable in experienced surgical centers for asymptomatic patients with chronic severe MR with preserved LV function (ejection fraction greater than 0.60 and end-systolic dimension less than 40 mm) in whom the likelihood of successful repair without residual MR is greater than 90% (Level B Evidence).

2. MV surgery is reasonable for asymptomatic patients with chronic severe MR, preserved LV function, and new onset of atrial fibrillation (Level C Evidence).

3. MV surgery is reasonable for asymptomatic patients with chronic severe MR, preserved LV function, and pulmonary hypertension (pulmonary artery systolic pressure greater than 50 mm Hg at rest or greater than 60 mm Hg with exercise) (Level C Evidence).

4. MV surgery is reasonable for patients with chronic severe MR due to a primary abnormality of the mitral apparatus and NYHA functional class III–IV symptoms and severe LV dysfunction (ejection fraction less than 0.30 and/or end-systolic dimension greater than 55 mm) in whom MV repair is highly likely (Level C Evidence).

Class IIb

MV repair may be considered for patients with chronic severe secondary MR due to severe LV dysfunction (ejection fraction less than 0.30) who have persistent NYHA functional class III-IV symptoms despite optimal therapy for heart failure, including biventricular pacing (Level C Evidence).

Class III

1. MV surgery is not indicated for asymptomatic patients with MR and preserved LV function (ejection fraction greater than 0.60 and end-systolic dimension less than 40 mm). In whom significant doubt about the feasibility of repair exists (Level C Evidence).
2. Isolated MV surgery is not indicated for patients with mild or moderate MR (Level C Evidence). **(2)**

<u>Indications of Surgery for Mitral Stenosis</u>

Class I

1. MV surgery (repair if possible) is indicated in patients with symptomatic (NYHA functional class III–IV) moderate or severe MS when:

1) percutaneous mitral balloon valvotomy is unavailable, 2) percutaneous mitral balloon valvotomy is contraindicated because of left atrial thrombus despite anticoagulation or because concomitant moderate to severe MR is present, or 3) the valve morphology is not favorable for percutaneous mitral balloon valvotomy in a patient with acceptable operative risk (Level B Evidence).

2. Symptomatic patients with moderate to severe MS who also have moderate to severe MR should receive MV replacement, unless valve repair is possible at the time of surgery (Level C Evidence).

Class IIa

MV replacement is reasonable for patients with severe MS and severe pulmonary hypertension (pulmonary artery systolic pressure greater than 60) with NYHA functional class I–II symptoms who are not considered candidates for percutaneous mitral balloon valvotomy or surgical MV repair (Level C Evidence).

Class IIb

MV repair may be considered for asymptomatic patients with moderate or severe MS who have had recurrent embolic events while receiving adequate anticoagulation and who have valve morphology favorable for repair (Level C Evidence).

Class III

1. MV repair for MS is not indicated for patients with mild MS (Level C Evidence).
2. Closed commissurotomy should not be performed in patients undergoing MV repair, open commissurotomy is the preferred approach (Level C Evidence). **(2)**

Surgical technique

The key to successful thoracic surgical procedures is adequate and proper exposure. A well chosen thoracic incision provides effortless and excellent exposure for almost any procedure. However, an ill chosen or an improperly placed or performed incision often leads to a difficult and frustrating procedure **(3).**

Approaching the Mitral Valve through Median Sternotomy

The patient is placed in a supine position on the operating table, and the arms can be either extended or placed by the patient's side. Although most anesthesiologists prefer to have one or both of the patient's arms extended for access to arterial and intravenous lines, it was found that by careful positioning and padding of the arms, it is possible to routinely place both arms at the patient's sides, thus improving the comfort of the operating team. By placing a small pad between the patient's scapula and tilting the head to one side, access to the upper end of incision is improved, especially in obese patients **(4).**

The intended line of incision may be identified with ink or by pinpoint skin depressions defining the starting point, midpoint, and completion of the incision every effort should be made to ensure that the incision is straight and exactly in the midline over the sternum. The sternal notch and tip of the xiphoid process are identified by palpation. The incision is begun approximately 2 cm below the sternal notch and extended approximately 2 cm beyond the distal tip of the xiphoid process and is usually extended with the electrocautery down to the sternal periosteum. A midline approach can be ensured by careful attention to the insertion points of the pectoralis major muscles onto the sternum; the incision should lie directly midway between these insertion points. This is preferable to estimation of the midline by palpation of the intercostal notches **(5).**

The incision is extended to the sternal periosteum and linea Alba with either a scalpel or electrocautery. Excessive use of electrocautery may increase the incidence of postoperative sternal infection **(6).**

The periosteum is scored in the midline with electrocautery, the linea Alba is divided at the xiphoid, and a plane is created behind the sternum at the suprasternal notch. Using a blunt finger dissection, a pathway is created above the suprasternal ligament and continued beneath the manubrium. No attempt at direct division of the suprasternal ligament by scissors, electrocautery, or other means is necessary. These techniques are to be avoided because of the risk of injury to the innominate artery as it passes upward to the neck. Division of the suprasternal ligament with the sternal saw is quite simple and much safer **(5).**

In most cases, the sternum is divided in a cephalic to caudal direction. The nose plate of the sternal saw is hooked underneath the suprasternal ligament, and the saw is grasped with both hands for stability. As the sternum is split, upward lifting on the sternal saw allows safe passage and helps avoid injury to the underlying pleura and mediastinal structures. It may be helpful to retreat slightly within the midportion of the sternotomy to allow release of any gathered pleura before completing the sternotomy. **(5).**

Alternatively the sternum can be divided using an oscillating saw or a Lebske knife, but both of these techniques are much less satisfactory **(3).**

It is useful to have the anesthesiologist temporarily deflate the lungs as the sternum is divided. This may help prevent entering the pleural spaces, particularly in those patients with COPD disease and hyperinflated lungs. Bleeding from the sternal periosteum is best controlled with electrocautery. In the past, bone wax was routinely used to control marrow bleeding, but its use has been abandoned on all but rare occasions because of the possibility of impaired wound healing.

Initiation of Cardiopulmonary Bypass and Valve Exposure:

After sternotomy, the pericardium is opened; the heart is cannulated for cardiopulmonary bypass. Arterial inflow is established by cannulation of the distal ascending aorta near the pericardial reflection. Double venous cannulation of the venae cavae by way of the right atrium is generally employed. In most adults a size 32 Fr cannula in the superior vena cava and a size 34-38 Fr cannula in the inferior vena cava provide excellent venous drainage and easy fit. Encircling of the venae cavae and their generous mobilization aid in the subsequent exposure of the mitral valve.

Umbilical nylon tapes secured with tourniquets can be used for subsequent upward retraction on the cavae. They may be tightened following cardioplegic arrest in order to minimize blood return into the right atrium and its subsequent delivery through the right heart and pulmonary circuit into the left atrium. The inter-atrial groove is dissected just anterior to the right superior pulmonary vein. The dissection is carried all the way to the level of the atrial septum. During this dissection, the core temperature of the body is reduced at 28 °C. After the dissection is completed, the aorta is cross-clamped and cardioplegic solution delivered through the aortic root **(7).**

After the cardioplegic solution is delivered, the tourniquets encircling the cavae are tightened and retracted upward to decrease the blood return from the right side. A transverse left atriotomy is performed and extended superiorly and inferiorly beneath the vena cavae. The mitral valve is then exposed by superior traction using a hand-held atrial retractor. In more lengthy cases, self-retaining retractors may be preferable **(7).**

Rewarming, removal of air, atrial closure and separation from cardiopulmonary bypass:

Once the operative procedure has been completed, whether repair or replacement of the mitral valve, rewarming of the patient is begun. In obese patients this process (rewarming) may have to start somewhat earlier. Removal of air from the heart is accomplished primarily through the opened left atrium. However, supplementary de-airing is also performed through the aorta. In preparation for de-airing, the valve is kept incompetent by means of a ventricular vent that is passed through the orifice of the valve. The atriotomy is then closed with the ventricular vent coming through the suture line or through a separate stab in the superior pulmonary vein. The vena caval tapes are loosened, and the perfusionist is instructed to restrict venous return to the pump so that the right heart fills with blood. The patient is rotated away from the surgeon and the head is declined so that air tends to rise towards the aortic root at the level of the cardioplegic cannula. The anesthesiologist then forces air out of the pulmonary veins into the left atrium by slow hyperexpansion of the lungs. Simultaneously, the surgeon gently massages the left ventricle and disturbs the left atrial appendage so that entrapped air evacuates through the vent. While cardiac filling and massage is ongoing, suction is placed on the aortic vent to evacuate air through the aorta. The aortic clamp is removed. Full venous return is then allowed to drain into the cardiopulmonary circuit, and the heart is collapsed. When cardiac contraction resume, the heart is allowed to fill while suction is maintained on the aortic root. When the patient is fully warmed and cardiac function restored, cardiopulmonary bypass is discontinued. Removal of air continues even after the heart resumes its function. Initially, this is performed with direct suction via the aortic root vent. After bypass is discontinued, this can be accomplished by allowing the aorta to bleed through the puncture site in the aortic root until the surgeon believes that adequate removal of air has been accomplished **(5).**

Closure of the Sternum:

After decannulation and hemostasis has been obtained, one or more large chest tubes are placed and led out through stab wounds at the lower end of the incision. The sternum is approximated with five to eight heavy stainless-steel wires passed through the sternum or, if one prefers or when the sternum is friable, around the sternum. If the wires are placed around the sternum, care must be taken to avoid injury to the internal mammary arteries. Traction is placed on these wires, and they are carefully tightened to achieve uniform approximation of the sternum. Care must be taken to avoid twisting the wires too tightly or they may cut through the sternum. Stainless-steel wire has been found to provide the most stable sternal closure when compared with other methods of closure including mersilene tape, stainless-steel bands, and plastic bands **(8).**

The twisted wires must be carefully turned down into the sternum so that they do not protrude externally and are not palpable, particularly in elderly thin patients or children. At the time of closure, care must be taken to avoid entrapment of pacing wires, and chest tubes. The linea Alba is approximated with non-absorbable sutures, as is the pectoralis fascia. Subcutaneous tissue may be closed with either continuous or interrupted absorbable sutures. For skin closure, either staples or standard suture is satisfactory, but subcuticular skin closure with a continuous absorbable suture provides a superior cosmetic result and avoids the necessity of removing sutures **(3).**

Approaching the Mitral Valve by minimally invasive techniques

Positioning

Patients are positioned supine with the right shoulder elevated and with the right arm at the patient's side **(9)**. Alternatively, the right arm may be supported over the head **(10). External** defibrillator pads should be placed prior to skin preparation to allow defibrillation in the presence of severe pericardial adhesions. One defibrillator lead is placed over the left anterolateral chest, and the other lead is placed under the right shoulder.

Anesthesia

Anesthetic management of port-access mitral patients differs from that of sternotomy patients in several points:

- First is the need to obtain single-lung ventilation if aortic cannulation is planned. These patients should be intubated with a dual-lumen endotracheal tube or with an endobronchial blocker placed in the right mainstem bronchus.
- Second, if the endoclamp is placed from the femoral artery with the possibility of endoclamp balloon migration, bilateral radial artery arterial lines should be placed to detect occlusion of the innominate artery should the endoclamp migrate distally If central aortic cannulation is planned, only a single radial arterial line is needed.
- Third, several other pressure transducers are needed for use of the endoclamp, and these include lines for aortic root pressure, endoclamp balloon pressure, and coronary sinus pressure. Finally, if desired, the anesthesiologist may place a percutaneous catheter into the coronary sinus during line placement **(11)**.

This technique has the advantage of providing retrograde cardioplegia without having an additional catheter in the surgical field. The disadvantages to percutaneous coronary sinus catheter placement include the learning curve in catheter placement, the variability of coronary sinus anatomy, and the additional cost of the coronary sinus catheter. In experienced hands, the coronary sinus catheter can be placed percutaneously 80% of the time. Also available is a pulmonary artery vent catheter which can be inserted by the anesthesiologist into the pulmonary artery through a venous sheath. In the future, anesthetic management of port-access patients may include regional analgesia such as paravertebral blocks to assist in the postoperative course. **(12).**

Incisions

Several different incisions have been used for mitral and tricuspid valve operations using port access.

The first incision is placed just lateral to the nipple over the fourth intercostal space (above the nipple in men and in the inframammary crease in most women). This anterolateral incision has the advantage of providing excellent access for central aortic cannulation and also provides the most direct and most lateral view of the mitral valve. The disadvantages of this incision are that it places the surgeon at a greater distance from the mitral valve and that more lateral cutaneous nerves may be injured, providing a somewhat wider area of medial numbness and paresthesia in some patients. **(12).**

The second commonly used incision is placed in the inframammary crease directly inferior to the nipple and just lateral to the mammary artery. This incision has the advantages of placing the surgeon closer to the mitral valve and of causing less medial paresthesia. Disadvantages include less access to the ascending aorta and a less favorable angle to view the mitral valve and subvalvular apparatus. The more medial incision is often used with femoral arterial cannulation and with greater use of the video camera to visualize the mitral valve (video-directed surgery) **(13).**

Rather than direct vision through the incision. Incisions can be made as small as 4 cm if the femoral artery is cannulated, and cannulation of the ascending aorta generally requires a 6-cm incision. An additional adjunct to provide exposure of the ascending aorta is to divide the fourth rib medially at the costochondral junction and then to enter the bed of the fourth rib. The rib is repaired at the end of the procedure.

A third approach to the mitral valve is to enter the right third intercostal space just lateral to the sternum if combined mitral and aortic valve procedures are planned **(14).**

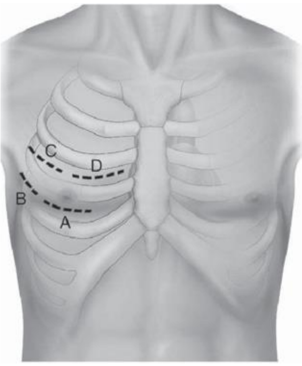

Figure (2): Four different incisions applicable to port access mitral procedures: (**A**) inframammary (**B**) infralateral (**C**) supralateral and (**D**) supramedial. The supramedial incision (**D**) is in the third intercostal space, and all others are in the fourth intercostal space **(15)**.

Pericardium opening

The pericardium is opened vertically from the diaphragm to the ascending aorta, keeping the incision at least 1–2 cm anterior to the phrenic nerve. If the ascending aorta is to be cannulated, the incision should be carried up to the innominate vein. Three lateral retraction sutures are placed on the posterior pericardial edge. The first is placed over the right superior pulmonary vein and is secured to the lateral corner of the skin incision. The second is placed halfway to the diaphragm and is passed through the chest wall using a 12-gage needle, a small hook, and a small clamp to secure the suture. The third suture is placed at the level of the superior vena cava and is passed through the third intercostals space as laterally as possible. If the ascending aorta is to be cannulated, the medial pericardium at the mid-ascending aorta is secured to the posterior sternum to provide aortic exposure. **(14).**

Femoral vessels cannulation

Femoral arterial cannulation is performed through a small 3- to 4-cm transverse incision in the groin between the inguinal crease and the inguinal ligament. The femoral artery and femoral vein are exposed and encircled with tapes, although tape placement is not necessary in a scarred and previously operated groin. Two concentric purse strings are placed in the femoral vein and artery using 5-0 polypropylene suture secured using tourniquets **(10)**

The femoral venous cannula is generally placed first. After heparinization, a guidewire is passed up the femoral vein into the superior vena cava using echocardiography, direct palpation, or direct vision. The 22 or 25 fr femoral venous cannula is then passed over the wire and through the purse strings to place the tip of the cannula 2 cm into the superior vena cava. The two 5-0 polypropylene suture tourniquets are then secured, and tapes on the proximal and distal vein are released, allowing continuous venous drainage of the leg and excellent hemostasis. Two concentric 5-0 polypropylene sutures are similarly placed in the common femoral artery, being careful that the diameter of the purse strings is less than one-half the diameter of the vessel to avoid vessel stenosis. After controlling the artery proximally and distally, an arteriotomy is made within the purse strings and is dilated to a diameter large enough to pass the arterial cannula. A 21 or 23 fr arterial cannula is then passed over a wire into the femoral artery, placing the cannula tip at least 2 cm into the femoral artery and away from any plaques or bends in the femoral artery. The 5-0 polypropylene tourniquets are then secured, and all tapes on the femoral artery are released so that the leg will be continuously perfused around the cannula. Both the arterial and venous cannulas can be placed as above if no difficulties are apparent, otherwise fluoroscopy may be necessary. Fluoroscopy is rarely needed for port access in experienced centers today. **(12).**

Central aortic cannulation

Central aortic cannulation has the advantages of eliminating endoclamp balloon migration, avoiding embolization and/or dissection due to aortic or peripheral vascular disease, avoiding femoral arterial injury, limb ischemia, and groin incision complications (seroma, infection, hematoma) **(19)**.

Central aortic cannulation has the disadvantage of requiring a somewhat larger incision and requiring the additional hardware of a specifically designed aortic cannula. Once the thoracotomy incision is made, the chest wall retractor is placed. A reusable-type retractor may be desirable here, as opposed to the earlier soft tissue retractor, to provide greater exposure of the ascending aorta by lifting upward on the superior chest wall. A 16-gage 6-in. needle is then passed through the first intercostal space at the midclavicular level, angling toward the desired cannulation site on ascending aorta to identify the optimal placement of the arterial line port. Care is needed to avoid the right internal mammary artery and vein. The arterial cannula should enter the aorta 1–2 cm proximal to the innominate artery with the aortic cannula directed toward the aortic valve. Angulation toward the aortic valve ensures that the endoclamp will pass toward the aortic valve and not down the aortic arch. Once this approach line is demonstrated with the 16-gage needle, a 2.5-cm transverse skin incision is made at the 16-gage needle puncture site, and an 11.5-mm trocar is passed through the former 16-gage needle track to provide a direct port for the aortic cannula. This port should point directly at the desired aortic cannulation site. The aortic cannula is then passed through the 11.5-mm port to ascertain that direct access to the desired cannulation site is possible without torque on the cannula. **(12).**

Attention is then turned to the femoral vein, which can be accessed percutaneously to avoid a groin incision. After heparinization, the common femoral vein is cannulated as described previously. Once the femoral vein is cannulated, a standard aortic purse string is placed at the desired cannulation site on the ascending aorta using two concentric 2-0 polyester sutures. The aortic cannula is passed through the 11.5-mm trocar in the first intercostal space so that the cannula introducer is centered in the aortic purse-string suture. The knife tip on the aortic cannula introducer is deployed only long enough to allow the introducer to reach the aortic wall. The introducer knife tip is then immediately withdrawn (to avoid injury to the back wall of the aorta), and the introducer and cannula are easily passed with a twisting motion into the ascending aorta. The 2-0 purse-string sutures are then passed through the 11.5-mm trocar and secured using plastic tourniquets placed through the trocar and secured with a heavy suture. Excellent aortic cannula stability is obtained. The placement of the venous cannula prior to aortic cannulation provides an additional source of vascular access should any bleeding be encountered. If an endoclamp is not to be used, then alternative aortic cannulas can be used that do not have a side arm for an endoclamp but that still have the knifetipped introducer.

Alternative venous cannulation

This includes placement of a second venous catheter into the superior vena cava via the right internal jugular vein **(13).** This is generally a 17 fr arterial-type cannula placed over a wire. Otherwise, a 28 fr angled plastic venous cannula can be placed through the chest wall or through the thoracotomy incision to provide standard cannulation of the superior vena cava. In this instance, a standard purse-string suture would be placed in the right atrium or in the superior vena cava after withdrawing the femoral venous cannula into the body of the right atrium. In those patients in whom femoral venous cannulation is not possible or desirable, the inferior vena cava can be cannulated through a right atrial purse-string suture with the cannula passed through the chest wall or through the thoracotomy incision. It is important that venous cannulation provide adequate drainage of the superior vena cava when the left atrium is retracted anteriorly, so that obstruction of the superior vena cava does not result.Assisted venous return should generally be used either via vacuum assist or by use of a Biomedicus centrifugal pump in the venous line. **(13).**

Aortic occlusion

Several alternatives exist for aortic occlusion. The ascending aorta can be occluded with an external clamp of either the Cosgrove or Chitwood **(10)** variety. These aortic clamps can be passed through the incision or through a separate stab wound lateral to the incision.

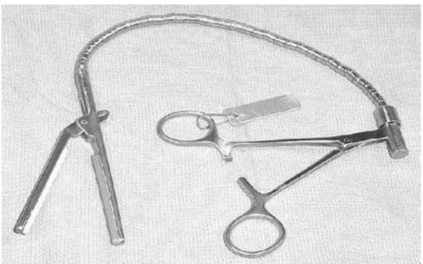

Figure (3): A flexible Cosgrove aortic external aortic clamp.

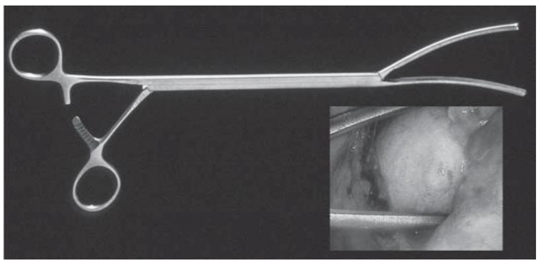

Figure (4): Transthoracic Chitwood clamp.

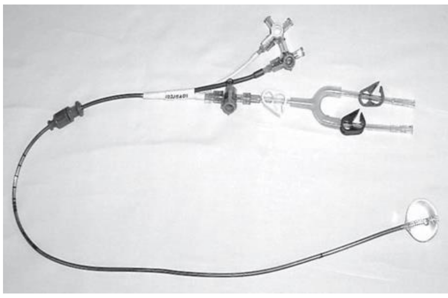

Figure (5): Transaortic balloon endoclamp (65 cm) **(15).**

Finally, the aorta can be occluded using an endoclamp passed through the aortic or femoral arterial cannula. Once the arterial cannula is placed, an endoclamp is passed through the "Y"-limb in the arterial cannula to position the end of clamp in the ascending aorta just above the aortic valve. Transesophageal echo or fluoroscopy can be used. If a femoral arterial cannula is employed, the endoclamp is passed over a wire. For direct cannulation of the ascending aorta, a wire is unnecessary. Once in the endoclamp is positioned, cardiopulmonary bypass is initiated using assisted venous drainage. With the transaortic endoclamp, the balloon is partially inflated, pulled back snugly against the tip of the aortic cannula, and then inflated to a volume sufficient to occlude the ascending aorta as demonstrated by transesophageal echo and/or direct palpation and inspection. With femoral cannulation, the endoclamp is inflated using transesophageal echo or fluoroscopy to ascertain positioning at least 1 cm above the aortic valve but proximal to the innominate artery. Once in place, slack on the femoral endoclamp catheter is tightened enough to prevent proximal balloon migration, without being so tight as to cause distal endoclamp balloon migration. Many centers, believe that intra-aortic balloon occlusion is associated with unnecessary increases in cost and complexity. Instead, we favored transthoracic aortic clamp occlusion as a safe, economical, and simple method for performing routine limited-access procedures **(10)**

<u>Cardioplegia</u>

If an external clamp is used, anterograde cardioplegia may be delivered through a standard cardioplegia cannula secured with purse-string sutures in the ascending aorta. Alternatively, a single dose of anterograde cardioplegia can be given using a spinal needle passed through the chest wall into the ascending aorta. **(16).**

Similarly, cardioplegia delivery can be handled in several ways. Ventricular fibrillation is an option when aortic occlusion cannot be obtained or when anterograde and retrograde cardioplegia are not feasible. Anterograde cardioplegia can be delivered through the endoclamp catheter or through a needle in the aortic root if an external clamp is used. Finally, retrograde cardioplegia can be delivered through a percutaneous coronary sinus catheter or through a retrograde coronary sinus catheter placed directly through a purse string in the right atrium. **(16).**

Valve exposure

With the heart arrested on cardiopulmonary bypass, the left atrium is opened adjacent to the interatrial groove. If needed, the left atriotomy can be extended superiorly behind the superior vena cava and inferiorly behind the inferior vena cava. The view of the left atrium and mitral valve is generally excellent and sufficient to perform complex repairs of the mitral valve and subvalvular apparatus especially by using minimally invasive atrial retractor. The mitral procedure itself is performed in a manner identical to that with sternotomy, with the exception that endoscopic instruments are required due to the distance to the mitral valve and due to the limited incision. These endoscopic instruments include endoscopic forceps, endoscopic needle drivers, endoscopic scissors, and endoscopic knot pushers. **(16).**

Deairing, closure, weaning from CPB

Upon completion of the mitral procedure, the left atrium is closed in a standard fashion with a left ventricular vent passed through the left atrial incision, through the mitral valve, and into the left ventricle. Several important adjuncts are used to air the heart. First, the entire thoracotomy field may be flooded with carbon dioxide throughout the case. **(17).**
Second, with the left atrium closed around the left ventricular vent by a tourniquet, suction is applied to the left ventricular vent with the aorta is still clamped. Ideally, some of the vent cannula holes should be in the left ventricle, and some holes should also be in the left atrium. Third, the patient is turned side to side while the perfusionist fills the heart with blood. Once the heart appears to be adequately de-aired on transesophageal echo, the patient is placed in Trendelenberg position, suction is applied to the aortic root vent, and

the aorta is unclamped. The patient is maintained in Trendelenberg position for 2 min after a weaning from cardiopulmonary bypass. Any residual air on echo can be aspirated through the aortic root vent or cleared down the right coronary artery. Once the heart is well de-aired on echo, the ventricular vent is removed, closure of the left atriotomy is completed, and the patient is weaned from cardiopulmonary bypass. **(17).**

Aortic decannulation is performed by tying the dual aortic purse-string sutures directly through the thoracotomy incision. The percutaneous venous cannula is simply withdrawn, and the subcutaneous tissue closed with absorbable suture. If a groin incision is used, the arterial and venous purse strings are tied, and the groin incision is closed in a standard fashion. The surgeon should have a low threshold to repair or patch any small, diseased, or narrowed femoral artery. A single 19 fr rubber drain may be placed in the pericardium and brought through the chest wall. The drain is placed so that both the pericardial space and the pleural space are drained postoperatively. A single 36 fr chest tube is left in the pleural space for the first 12–24 h. The fourth rib is repaired with a #4 sternal wire if the rib was divided. The skin incision and any other port sites are closed with absorbable sutures. **(17).**

Postoperative care

Postoperative management differs little from that of standard sternotomy patients. Because bleeding is generally minimal, the pleural drain is usually removed within 12 h and the 19 fr drain is removed after 3–5 d. Postoperative pain appears to be similar to sternotomy for the first 1–3 d, and thereafter appears to be less than with sternotomy **(18)**

Patients appear to have greater arm use and earlier mobility than with sternotomy **(19).**

Future& robotic surgery

Many continue to advocate that port access is simply a steppingstone to a totally endoscopic repair of the mitral valve. The goal of totally endoscopic mitral surgery is becoming possible using port access, but only with robotic assistance **(10).** At several institutions, port access has been used to perform mitral operations through a small thoracotomy using robotic assistance to manipulate the camera or surgical instruments **(20).** Robotics in turn could greatly facilitate training of younger surgeons in minimally invasive techniques. Robotics can for the first time allow remote surgery with the operating surgeon and the patient in two different locations **(21).**

However, current robotic procedures have disadvantages of expensive and bulky instrumentation, longer operating times, need for a groin incision, and remaining technical issues such as limited facility with knot tying. The ultimate market share enjoyed by port access for isolated mitral valve surgery will be a balance between patient demand for the procedure vs limited time, limited resources, and limited experience of providing physicians and hospitals. Efforts to simplify the port access platform will continue over the next few years as robotic technology evolves. As instrumentation and imaging improve, port-access approaches to the mitral valve may have broader appeal. It is clear that subsets of patients can benefit from the port-access approach to mitral operations, and continued development of techniques, equipment, and education will help define these cohorts. **(21).**

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