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Review Article

Minimally Invasive Mitral Valve Surgery: An Update

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Abstract: Minimally invasive mitral valve surgery (MIMVS) was introduced in the mid-1990s to refer to a variety of surgical techniques that avoid full sternotomy through smaller or alternative chest wall incisions, as an attempt to reduce complications, but at the same time preserve outcomes of the full sternotomy approach. In this review, different aspects of MIMVS are discussed in relation to its approaches (right parasternal incision, lower ministernotomy, right anterolateral minithoracotomy and left posterior minithoracotomy) as well as strategies (mini-incisions, video-assistance, video direction with robotic assistance and telemanipulation) passing through more than 2 decades of continuous evolution. In the current practice MIMVS shows similar outcome to conventional surgery with even more superior results regarding blood loss, ICU and hospital stay, as well as functional recovery. The accumulating experience with MIMVS encouraged surgeons to extend the application of these techniques to high-risk patients, redo surgeries, concomitant double or triple valve procedures as well as combined coronary artery and mitral valve diseases in a hybrid approach, reducing the need for full median sternotomy. In addition there is an emerging trend of transcatheter valve implantation in the mitral position with small reports of valve-in valve or valve-in- ring implantation as well as valve replacement in case of severe MAC. This new trend may establish itself in the future as a modality in treating native mitral valve diseases in high risk patients. Therefore it is recommended for cardiac centers to build up a program for MIMVS in order to fulfill the recent requirements of cardiac surgery.

Keywords: Minimally Invasive Mitral Valve Surgery, Port Access, Totally Endoscopic Mitral Valve Surgery, Robotic Mitral Valve Surgery

1. Introduction

Mitral valve surgery (MVS) has passed through major advances over the past 2 decades regarding its indications, repair techniques, prosthetic valves and surgical approaches. [1] Median sternotomy has been the standard approach with the best outcome in heart surgery for more than 30 years. It allows more exposure to the heart and great vessels, easier arterial and venous cannulation for cardiopulmonary bypass and better myocardial protection. However this approach is associated with some drawbacks in the form of postoperative bleeding, postoperative pain, sternal dehiscence, long functional recovery and long (sometimes non-cosmetic) scars. [2] Also owing to the major advancements achieved in percutaneous procedures including transcatheter aortic valve implantation (TAVI) and MitraClip, surgeons were forced to adopt new less aggressive techniques to cope with patient demands and maintain their role in treating heart diseases. Therefore, the term 'minimally invasive mitral valve surgery' (MIMVS) was introduced in the mid-1990s to refer to a variety of surgical techniques that avoid full sternotomy through smaller or alternative chest wall incisions, as an attempt to reduce complications, but at the same time preserve outcomes, of the full sternotomy approach. [3]

Hence, MIMVS is designed to cause less surgical trauma and preserve more chest wall integrity. This would be reflected as less postoperative pain, less postoperative bleeding or need for blood product transfusion, smaller more cosmetic wounds and better postoperative respiratory functions. At the end, shorter ICU as well as hospital stays, faster recovery, lower costs and earlier return to normal activity would be achieved. [4&5] On the other hand exposure of the mitral valve should not be compromised, the ability to repair the valve when possible should not be sacrificed and the mortality as well as the morbidity of MVS should not be increased. [6]

However, these techniques are minimally invasive for the patients but are maximally stressful to the surgeons. They are in general more complex and require a learning curve due to the use of special instruments;the non-traditional exposure of the mitral valve and in many cases the non-familial cannulation of peripheral vessels. These techniques were first applied to highly selected patients with low risk profile to ensure the best outcome. Nevertheless, patient population referred for surgeons has changed towards a high-risk profile of older patients with more co-morbidities or previous heart surgeries, so these approaches are now to be applied to patients with higher risks. [7&8]

The aim of this article is to spot the different aspects of MIMVS in relation to its approaches and strategies passing through more than 2 decades of continuous evolution since the mid-1990´s till now. The past experiences, the current status and the future trends of these techniques are thoroughly discussed in order to emphasize their importance for cardiac surgeons to fulfill the recent requirements of the cardiac surgery specialty.

2. Different Approaches in MIMVS

Minimally invasive cardiac surgeries started with the beginning of the era of laparoscopic cholecystectomy in the early 1990s. The first "minimally invasive mitral valve repair" was reported by Carpentier et al in 1996. [9]

Since then, many incisions were involved in MIMVS. The most common incision is the right minithoracotomy, followed by the lower ministernotomy and the parasternal incision. Recently there is a renewed interest in the left thoracotomy approach.

In general, an ideal incision should have the following criteria;

-Small in size with good cosmoses and healing.

-Permits access to all cardiac areas.

-Provides a traditional exposure of the heart.

-Safe and reproducible with the ability to be submitted to all patients.

-Requires minimal need for special equipments.

-Allows rapid and easy conversion to the traditional (full sternotomy) approach.

-Preserves the integrity of the thoracic cage improving postoperative respiratory mechanics and allowing rapid recovery of the patient and early return to work.

-Does not compromise the ability to repair the valve.

When applying those criteria to incisions used in MIMVS, no incision will fulfill all criteria. Each incision has its advantages and disadvantages. [10]

2.1. Right Parasternal Approach

This approach was originally described by Navia and Cosgrove in 1996. [11] In the supine position a 5 to 8 cm vertical incision is made along the right edge of the sternum. The pectoralis major muscle is dissected away from the sternum to expose underlying costal cartilages. The 2^{nd} till 4^{th} costal cartilages according to the patient's anatomy are then resected. The right internal thoracic pedicle is divided at the upper and lower intercostal spaces and the intercostal muscles are incised 3 to 4 cm lateral to the mammary pedicle to open the right pleural space. The pericardium is now incised parallel to the phrenic nerve and is suspended with multiple retraction sutures to pull the heart slightly to the right into the field. Cannulation can be performed femoro-femoral using long cannulae inserted into groin vessels or a special arterial cannula may be inserted directly into the ascending aorta by means of Seldinger´s technique and a long venous cannula is to be inserted into the femoral vein. To improve venous drainage a right-angled cannula can be inserted directly into the superior vena cava. Myocardial protection can be achieved via antegrade cardioplegia through the aortic root or through retrograde cardioplegia into the coronary sinus under direct vision. The mitral valve is exposed usually through the right atrium and atrial septum or less commonly directly through left atriotomy. This approach has the advantage of attacking the mitral valve with the use of standard instruments and techniques. [12]

However, it was abounded by most centers due to its complications and the appearance of more attractive minimally invasive approaches. First this approach may be not suitable for very obese or very muscular chest wall. Second, sacrifice of one internal thoracic artery appears to be hazardous especially with the growing tendency to use bilateral mammary arteries in current practice of CABG operations if these patients develop ischemic heart diseases in the future. Third resection of costal cartilages may be followed by instability of a portion of the anterior chest wall due to lung herniation. This manifests by slight bulging of the chest wall during coughing and leads to bad cosmetic results. [13]

2.2. Lower Ministernotomy

This technique was first published by Doty et al 1998. [14] In this technique the patient is placed in the ordinary supine position. A midline incision of 6-8 cm in length is made over the lower sternum 2cm distal to the manubrio-sternal angle till 2 cm proximal to the base of the xiphoid process. The sternum is divided vertically from the xiphoid process till the 3rd intercostal space and then at that point transversely to the right taking care not to injure the internal mammary artery using an oscillating saw (inverted J- sternotomy). A small retractor is inserted and the pericardium is then opened from the diaphragm till near the aortic reflection superiorly. Retraction stitches on the edges of the pericardial sac help to bring the heart anteriorly. To facilitate the exposure of the heart the intact upper sternum may be elevated using a modified Favaloro retractor. Cannulation can be achieved either directly to the ascending aorta and right atrium or through the groin vessels with special long cannulae. Myocardial protection can also be done through antegrade administration of cardioplegia solution to the aortic root or through a retrograde cannula inserted directly into the coronary sinus. In case of limited space the aortic occlusion clamp may be brought into the chest through a separate stab incision. The mitral valve can be accessed through left atriotomy or preferably transeptally. The rest of mitral surgery is similar to the classic approach.

This approach provides traditional exposure of the mitral valve as well as the tricuspid valve and requires no special instruments permitting all procedures on the mitral valve. [15] Therefore lengths of CPB and aortic cross clamp are not much prolonged. Another advantage of this approach is the rapid and easy conversion to full sternotomy if complications occurred or the exposure was inadequate. However, although this approach is smaller than the median sternotomy and preserves more the chest wall, yet gives not much better cosmetic results and is amenable to keloid formation. This is why it may be not the one preferred by young females. Also one of its disadvantages that it may be not suitable in patients who underwent previous cardiac surgery through sternotomy or patients with dilated left ventricular end-diastolic dimension ≥ 75 mm. [16]

2.3. Right Anterolateral Minithoracotomy

The patient is positioned in a mild left lateral position. A 5-7 cm incision is made in the 4th or 5th ICS. A soft tissue retractor is then inserted into the incision followed by a small chest retractor. A stab incision is done in the 3rd or 4th ICS in the mid-axillary line for the insertion of the transthoracic aortic clamp (e.g. Chitwood clamp). Another incision in the 2nd or 3rd ICS may be made for a camera. Regarding cannulation some centers cannulate both femoral artery and femoral vein in the groin with special long cannulae either open or percutaneously using Seldinger´s technique. Positioning of the venous 2-stage cannula in the right atrium with the tip in the superior vena cava is guided with transesophageal echo. Others prefer to cannulate centrally the ascending aorta under direct vision beside femoral vein cannulation in the groin to avoid retrograde arterial flow which may be condemned for the occurrence of cerbrovascular insults. [17] However direct cannulation of the ascending aorta is to be avoided in case of patent saphenous vein grafts, severe adhesions or severe calcifications of the ascending aorta.

In case of a combined procedure in the right atrium, an additional cannula is inserted in the right internal jugular vein preoperatively by the anesthetist and both cavae are snared with special devices. In redo cases occluding both cavae may be challenging due to adhesions and in such a case a special double-stage femoral venous cannula with 2 separate distal and proximal perforated sections separated by a non-perforated segment facilitates drainage of both cavae simultaneously without snaring. [18] The use of this cannula avoids complications of the insertion of a right internal jugular vein cannula, such as bleeding due to carotid artery injury.

After full heparinisation, CPB is instituted and the lungs can be deflated.

For myocardial protection antegrade cardioplegia is delivered directly in the ascending aorta with a special cannula after aortic clamping. Hypothermic ventricular fibrillation or beating heart surgery may be used in patients with patent coronary artery bypass grafts or severe calcification of the ascending aorta. [19] Retrograde cardioplegia is another option administered under echocardiographic guidance directly from the incision into the coronary sinus. The mitral valve is then exposed through a left atriotomy with the aid of an atrial retractor supported by an arm inserted in the thorax through a right parasternal stab incision. The mitral procedure can now be performed under direct vision with thoracoscopic assistance.

Additional surgical ablation as well as left atrial appendage exclusion in case of atrial fibrillation can be safely performed with endocardial left atrial lesions using for example monopolar radiofrequency.

Deairing of the heart at the end of the procedure can be achieved by manipulating the position of the patient head, inflating the lungs and aortic venting with or without transmitral venting. Adequate deairing should be confirmed by transesophageal echo.

This minimally invasive approach has gained high acceptance over the last years and has been proved to be safe offering a good view of the mitral valve and allowing all types of repair techniques. [20]

Disadvantages of this approach include more surgical difficulty requiring longer learning curve due to the use of special long-shafted instruments and the non-traditional approach to the mitral valve as well as the longer CBP, cross-clamp and total procedure times. However despite the longer distance to the mitral valve, experts in this approach find the exposure of the mitral valve more anatomical than with sternotomy. Furthermore cannulation of the groin vessels adds some incidence of complications related to peripheral cannulation. [21&22]

Moreover, there is a debate about the increased incidence of cerebrovascular accidents occurring with minimally invasive mitral valve techniques due to fermoral cannualtion especially in the presence of peripheral vascular disease or as a result of performing surgery on a fibrillating heart. Contradictory reports from different centers make this issue still unclear. [23-26]

2.4. Left Posterior Thoracotomy

Approaching the mitral valve through a left thoracotomy has been accomplished in the 1960s to perform mitral valvuloplasties. However, as median sternotomy became the standard approach for cardiac surgeries, the left thoracotomy approach lost its popularity. [27]

After evolution of minimally invasive mitral valve techniques, the right minithoracotomy is now the approach of choice for the mitral valve in most centers. However in some cases a right thoracotomy approach may be relatively contraindicated e,g. prior right-sided mastectomy with chest wall radiation or multiple-time redo mitral valve surgery (first redo after sternotomy can be done through right thoracotomy but subsequent re-operations through the same right thoracotomy are difficult). In such cases avoiding a sternotomy may be still achieved through a left posterior minithoracotomy. [28]

In addition left minithoracotomy is an attractive approach for minimally invasive combined mitral and coronary or left ventricular procedures as it allows access to the descending aorta for placement of proximal anastomoses. [29] Therefore, recent reports renewed the interest in left thoracotomy approach for the mitral valve and showed that it is safe as a minimally invasive technique.

In this technique the patient is positioned in right lateral position and a left posterolateral mini-thoracotomy incision of 6-8 cm is made in the fourth or fifth intercostal space. The lung is then retracted inferiorly to expose the heart. The pericardium is now opened posterior to the phrenic nerve and retracted with retention sutures. CPB is instituted either by direct cannulation of the descending aorta and the left pulmonary artery or by cannulating both femoral artery and vein in the groin. Myocardial protection is accomplished either through hypothermic fibrillation or administration of antegrade cardioplegia after balloon endoclapming of the aorta. The cardioplegia can be given also retrograde via a transjugular coronary sinus catheter. The left atrium is finally opened along the base of the left atrial appendage and a self-retaining retractor is placed to expose the mitral valve which can be dealt with in a standard fashion.

Left thoracotomy approach for the mitral valve carries the advantage of a wider angle of vision and a shorter distance to the mitral valve although the orientation of the mitral valve is inverted in comparison to the exposure from the right side. On the other hand this approach has the disadvantage of lack of access to the ascending aorta for direct cannulation and cross-clamping. [30]

3. Strategies of MIMVS

Chitwood and Rodriguez proposed a classification of four levels of minimally invasive cardiac surgery (MICS); namely: direct vision using a mini-incision of 8-10 cm, video-assisted procedures using a microincision of 4–6 cm, video-directed and robotic-assisted procedures as well as robotic telemanipulation procedure. [31]

3.1. MIMVS Through a Mini-incision

This level included small incisions avoiding full sternotomy in order to improve cosmoses, lessen pain and fasten recovery as discussed above.

3.2. Video-Assisted MIMVS Through a Micro-incision

In1996, Carpentier was the first to use video assistance in mitral valve repair through right minithoracotomy. A stab incision was done in the 3rd space in the anterior axillary line for the insertion of a trocar followed by the camera. [9]

In 1997, a new system called Port Access emerged as a new revolution in minimally invasive cardiac surgery. Port Access system incorporated endoscopic long-shafted surgical instruments together with endovascular cardiopulmonary system that enabled heart surgery through minute intercostal incisions (ports).

Endovascular CPB system included special catheters and cannulae for endoclamping of the aorta and endovascular retrograde administration of cardioplegia.

Endoaortic clamping is done by using a special femoral arterial cannula with a side arm through which a guide-wire is advanced to the aortic root under echocardiographic guidance. An endoaortic balloon is then introduced over the guide-wire to occlude the aorta and deliver antegrade cardioplegia at the same time. This device allows also drainage of the left ventricle. Endoaortic clamping is especially beneficial when the ascending aorta cannot be safely mobilized.

Endovascular administration of retrograde cardioplegia is performed through the right internal jugular vein into the coronary sinus by the anesthesiologist. [32]

As a result of advances of experience with this technique a rib-spreading anterior minithoracotomy has been modified towards a totally endoscopic approach. Port placement is done simultaneously with femoral cannulation. The camera port together with the CO_2 insufflator is placed in the 4th ICS 2 to 3 cm lateral to the nipple (in the infra-mammary crease in females). The working port incision is placed in the same intercostal space 4 cm lateral to the camera port. With a finger in the chest cavity through the working port, a left instrument post is placed one interspace above and halfway between the shoulder and the camera port as well a right instrument port is placed two or three interspaces below and near the anterior axillary line. A transthoracic cross-clamp is introduced via a stab wound in the axilla. [33&34]

3.3. Video-Directed Robotic-Assisted MIMVS

The need for frequent adjustments to the left atrial retractor and videoscope through the use of passive articulating arms in the port-access technique distracts the surgeon and increases the total procedure time.

Therefore, in 1997, Mohr was the first to use the voice-controlled robotic arm; AESOP 3000 (automated endoscopic system for optimal positioning; Computer Motion, Inc., Santa Barbara, CA, USA) to control a three-dimensional videoscope (Karl Zeiss, Oberkochen, Germany) inserted through a 10 mm port at the second right intercostal space in the anterior axillary line. [35] The robot was mounted to the operating table and its motion was controlled by simple one- or two-word commands from the surgeon. This resulted in steadier visual field and reduced the time required to adjust the camera as well as the number of removals and reinsertions of the camera after cleaning. In addition to the achieved less operative time, this technology opened the door to solo cardiac operations eliminating the role of an assistant. [36]

In 2001 Felger and colleagues introduced the da Vinci Robotic Surgical System (Intuitive Surgical, Inc, Sunnyvale, Calif) to minimally invasive mitral valve repair. [37] The three dimensional vision with magnification of the operative field and articulated wristed instruments provided with this system improved much manipulations at the level of the valve. In the USA robotic-assisted mitral valve repair was started by Chitwood and colleagues and obtained FDA approval in December 2002. [38] The original model of the da Vinci System controlled the handle of the atrial septal roof retractor (Cardiovations, Irvine, Calif). The second generation, da Vinci

Si HD, had a fourth articulating arm which functioned as a movable left atrial roof retractor placed in the 5th ICS medial to the camera port offering more efficient manipulation of retraction to improve visualization as well as to release retraction during testing the valve. [39]

3.4. Totally Robotic MIMVS (Telemanipulation)

Here the surgeon, assisted by a 3D visualization, manipulates from a console (away from the patient) several robotic arms attached to working ports inserted into the chest (telemanipulation). Robotic mitral valve surgery implied all previous minimally invasive techniques in addition to the da Vinci robotic telemanipulation system. Co-ordination between team members, the anesthesiologists, operating room staff, perfusion, and the patient-side assistant is mandatory. All valve repair techniques can be performed robotically. The only unique repair technique in the robotic MIMVS is the use of Nitinol U-clips (Medtronic Inc., Minneapolis, MN) in place of sutures to fixate flexible annuloplasty bands. [40]

Advantages of this system include tremor filtration as well as avoidance of the fulcrum effect of long endoscopic instruments on mitral leaflets. On the other hand disadvantages of robotic surgery include prolonged operative time due to the complexity of the procedure and the extensive cost of the system which makes robotic MVS not applicable in all cardiac centers. Even after subtracting the saved costs of reduced hospital stay and blood transfusions from operative costs, operations performed by the da Vinci-system cost 15% more than other approaches. Therefore only high-volume centers can adopt this technique. [41]

Relative contraindications included pleural adhesions e.g. due to previous right pulmonary surgery, poor pulmonary or ventricular function, aortic insufficiency and pectus excavatum. [42]

4. Current Status of MIMVS

Many recently published studies comparing results of MICS to conventional surgery showed clearly similar outcome with superiority of the minimally invasive group regarding blood loss, ICU and hospital stay, as well as functional recovery. For example in the study done by Svensson et al 2010 comparing 2124 patients underwent MIMVS with 1047 patients received conventional mitral valve surgery using a propensity score based on 42 factors to get well-matched patient pairs, in-hospital mortality was similar (0.17% in the minimally invasive group and 0.85% in the conventional group). Incidence of stroke ($P=0.8$), renal failure ($P>0.9$), myocardial infarction ($P=0.7$), and infection ($P=0.8$) were also comparable. On the other hand, 24-hour tube drainage was less after minimally invasive surgery (median, 250 vs 350 mL, $P<.0001$). Also fewer patients received transfusions (30% vs 37%, $P=0.01$). More patients received minimally invasive surgery were extubated in the operating room (18% vs 5.7%, $P<0.0001$). Postoperative pain scores were lower ($P<0.0001$) after minimally invasive surgery. [43]

This accumulating experience with MIMSV encouraged surgeons to extend the application of the minimally invasive techniques now to high-risk patients, redo surgeries and concomitant double or triple valve procedures [44], reducing the need for full median sternotomy. Also when it comes to combined coronary artery and mitral valve diseases, a hybrid approach of percutaneous coronary intervention and MIMVS has been suggested as an alternative to the standard approach of combined coronary artery bypass grafting and mitral valve operation through median sternotomy. [45]

Minimally invasive redo mitral valve surgery through right mini-thoracotomy or Port Access is proved to be safe and is associated with reduced ICU stay, hospital stay and postoperative complications. MIMVS allows direct access to the mitral valve to perform redo mitral valve surgeries without the need for mobilization of the whole heart as in the standard approach. In the study done by Vallabhajosyula et al 2015 in Pennsylvania, 409 patients requiring second-time or more mitral valve operations were included. Of these patients, 67 underwent the procedure through port access technique, and 342 through redo sternotomy approach. The rate of re-repair among both groups was similar (19% vs 22%, $p=1$). CPB and aortic cross-clamping times were lower in the port access group (153 ± 42 minutes vs 172 ± 83 minutes, $p=0.07$) and (104 ± 38 minutes versus 130 ± 71 minutes, $p < 0.01$) respectively. Mortality was lower in the port access group, although not significantly (3.0% vs 6.0%, $p< 0.5$). The rate of postoperative stroke was also similar (3.0% vs 3.2%, $p = 1$). The mean hospital length of stay was 11 ± 15 days versus 14 ± 12 days ($p=0.07$). [46]

Regarding patients with operative risks, Santana et al showed in their series of 160 patients that obese patients underwent minimally invasive aortic or mitral valve surgeries had similar results, compared to non obese patients, in relation to cross-clamp time, CPB time, ICU stay, in- hospital mortality, incidence of prolonged intubation and re-intubation as well as rate of blood transfusion. [47] In another series they found comparable outcomes between patients with low ejection fraction after minimally invasive mitral valve surgeries and those after median sternotomy in concern of 30-day mortality and rate of postoperative complications. [48]

Similarly elderly patients underwent minimally invasive valve surgeries experienced in the study done by Lamelas et al in 2011 low morbidity and mortality. [49]

5. Future Trends of MIMVS: Transcatheter Valve Implantation in the Mitral Position

Transcatheter aortic valve implantation has been well-established as a modality of treatment of aortic valve diseases in high-risk patients in whom surgery would carry more risks. [50]

Nowadays some reports of transapical or percutaneous mitral valve delivery as a valve-in-valve or valve-in-ring technique are emerging. The reason for this new concept arises from the fact that redo-surgery to replace a degenerated mitral bioprosthesis or failing repaired mitral valve with a ring may be deemed to be dangerous in elderly, frail patients with multiple co-morbidities. [51]

Also severe mitral annular calcification (MAC) can be hazardous. Surgical repair is usually impossible and replacement with conventional technique is challenging. Sometimes the surgeon is unable to pass suture needles through heavy calcium and decalcification of the annulus carries the risk of disruption of the atrioventricular (AV) groove, circumflex artery injury, paravalvular leak, and stroke. Therefore, some recent small series now report the deployment of the balloon-expandable Sapien valve (Edwards Lifesciences) anchored by radial force in the native mitral valve. [52-54]

These new trials of endovascular implantation of a transcatheter valve in the mitral position may represent, in a similar fashion to aortic valve, an option to treat native mitral valve diseases in the future in high risk patients or patients in whom the ordinary mitral valve surgery is regarded as challenging. This endovascular technique is still evolving and reports are needed to establish clear indications as well as outcomes in comparison with the well-known mitral valve surgery.

6. Learning Curve and Training Program in MIMVS

MIMVS has gained its acceptance among cardiac surgeons worldwide as well as the attention of both cardiologists and cardiac patients. It is a must for cardiac surgeons now to be able to offer these techniques to their patients. Therefore most cardiac centers now are implementing a training program to practice MICS.

Since MICS is a team process like all cardiac surgeries, so the first step in starting such a program is to choose a group of interested experienced as well as young surgeons in addition to anesthesiologists, perfusionists, and nurses to be dedicated to the minimally invasive team.

The training starts with an introduction to the program followed by online training. The next step is a live training with observation of real cases at one of the leading centers in MIMVS followed by practicing the techniques in an animal lab.

It is then recommended that the most experienced surgeon starts the initial cases with assistance of the dedicated team. First cases should be selected to have low risks with suitable anatomy in order to obtain good results and overcome the learning curve. All cases in the center planned to receive MIMVS should be referred to the selected team, as a large number of cases within a short time is needed to establish a convenient progress of the program. All operation steps are to be agreed upon and standardized in order to achieve co-ordination and harmony among the team which has a great impact on shortening the time and improving the outcome of operations. Any modifications in the technique according to data analysis have to be discussed and addressed by the entire team to reach the best results. [55] As experience grows and operative time shortens more complicated cases can be operated.

The final step in the program is to train assistants themselves to practice MIMVS.

It is clear that senior consultants have to maintain patients' safety and outcome. However it is of importance to build up a new generation of minimally invasive surgeons. It is recommended that the trainees initially start to institute, under supervision, cardiopulmonary bypass in MICS before gradually proceed to perform simple MIMVS cases with the consultant at first scrubbed at the operation table and later on not scrubbed but present at the operating theater. The use of video-assistance helps the senior staff to monitor the performance of the trainee even if was not scrubbed. [56]

Results from studies on that issue showed that the trainees had longer ischemic and bypass times than the consultants. However this would not significantly affect the surgical outcome with low risk patients in concern of building up future minimally invasive surgeons. [57]

7. Conclusion

It has become a matter of survival to cardiac surgeons to learn and adopt minimally invasive techniques in general and MIMVS in particular if we want to maintain the surgical role in treating patients in our specialty. These techniques are now proved to give equivalent outcome to that of median full sternotomy with even better results regarding postoperative pain and bleeding, hospital stay, cosmetic appearance and functional recovery.

This superiority of the outcome of minimally invasive mitral valve surgery even in high risk and redo patients over conventional mitral valve surgery resulted in disappearance of many contra-indications and exclusion criteria for MICS. The costs of special equipments and longer operative time encountered in minimally invasive surgery can be neutralized on the other hand by shorter hospital and ICU stay, earlier return to work, less blood transfusion, increasing case load (high volume) and learning curve.

Furthermore, as progress in trans-catheter valve procedures continues MIMVS would become the standard of care in mitral valve surgery.

To establish a learning curve in MIMVS a special team of surgeons, cardiac anesthesiologists, perfusionists, and nurses should be dedicated to build up more experience and achieve better results. Training should be planned carefully and should follow certain steps in order to overcome the learning cave and reach a good outcome.

Abbreviations

AV = atrio-ventricular
CPB = cardio-pulmonary bypass
ICS = inter-costal space
IVC= inferior vena cava
MAC = mitral annular calcification
MICS= minimally invasive cardiac surgery

MIMVS = minimally invasive mitral valve surgery
MVS = mitral valve surgery
SVC= superior vena cava
TAVI = transcatheter aortic valve implantation

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