Do Minimally Invasive Approaches Improve Outcomes of Heart Valve Surgery?

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With the development of techniques and technologies in the past decade, minimally invasive valve surgery (MIVS) has become a well-established surgical option for heart valve disease. Unlike emerging transcatheter valves, MIVS still requires cardiopulmonary bypass and cardiotomy. The only difference between minimally invasive and conventional valve operations is whether a full sternotomy is avoided or not. The minimally invasive approach has been shown to have some beneficial effects such as reduced blood transfusion and faster postoperative recovery. However, these could be limited and outweighed by the potential adverse effects of small access. Careful selection of patient, approach and perfusion strategy based on thorough preoperative assessment and each surgical team experience is necessary to perform MIVS safely. (Circ J 2013; 77: 2232–2239)

Key Words: Aortic stenosis; Minimally invasive surgery; Mitral valve; Valvular heart disease

The number of patients with heart valve disease has been increasing in many developed countries because of rapid aging of the population and well-developed medical screening systems. Recent advances in technology offer the new option of transcatheter treatment for heart valve disease. However, because of the lack of established standards of efficacy and durability, the indication of transcatheter procedures is still limited to patients who are at high risk for surgery. Thus, surgical treatment is likely to remain the gold standard for treating advanced heart valve disease. Traditionally, heart valve surgery has been performed through a median full sternotomy and with cardiopulmonary bypass (CPB). This traditional approach provides surgeons excellent exposure and comfortable access, and is well tolerated with minimal discomfort and a low incidence of complications.

Minimally invasive valve surgery (MIVS) was introduced in mid-1990s and has become a well-established surgical option for heart valve disease with the development of techniques and technologies during the past decade. Minimally invasive cardiac surgery is defined as any cardiac operation performed without a full sternotomy or without CPB. MIVS, in general, refers to a cardiac valve operation without a full sternotomy, but still requires CPB and cardiotomy, and the only difference between MIVS and conventional valve surgery is whether a full sternotomy is avoided or not. In that sense, there is an argument that the term “minimally invasive” is misleading, and other terms such as “small incision” and “minimal access” are sometimes preferred. Thus it is important to discuss whether MIVS improves surgical outcomes without compromising the established quality of conventional valve surgery. Herein, we review the current evidence regarding the risks and benefits of MIVS and discuss the clinical impact of avoiding a full sternotomy in heart valve surgery.

Surgical Techniques

The approaches of MIVS vary from direct vision to totally endoscopic and robotic surgery. Many surgeons still prefer direct-vision approaches because those are more accessible and generally the operating time is shorter than with endoscopic/robotic approaches. In direct-vision MIVS, surgeons operate by looking at the valve directly through a small incision, usually spreading the sternum or ribs using a metal retractor to obtain direct visualization and working space.

Partial Sternotomy and Parasternal Incision

Upper hemisternotomy is the most common minimally invasive access to the aortic valve, and it is also useful for mitral valve, double-valve (aortic and mitral), triple-valve (aortic, mitral and tricuspid) and reoperative aortic valve operations. There are some variations in the shape (eg, J-shaped, L-shaped, inverted T-shaped, reversed C-shaped and V-shaped) and size (down to 3rd, 4th and 5th intercostal space) of the upper hemisternotomy. At our institution, we make a 6–8 cm skin incision in the midline of the chest and divide the sternum down to the 4th intercostal space. We divide the sternum to the right side (J-shaped, Figure 1A) or left side (L-shaped) according to the location of the aortic valve on preoperative CT. CPB is instituted with central aortic and central/peripheral venous cannulation. Cardioplegic asystole is obtained with a regular aortic cross-clamping and a combination of antegrade and retrograde cardioplegia administration. Lower hemisternotomy (Figure 1B) is another partial sternotomy incision that is used for mitral and tricuspid valve...
Minimally Invasive Valve Surgery

Right thoracotomy is the most common minimally invasive access to the mitral valve. The mitral valve is usually well exposed through this access because it is facing the right side of the chest in its natural position. For direct-vision access to the mitral valve, usually the 4th intercostal space of the right anterolateral chest is entered (Figure 2A) with a 5–8 cm skin incision. The incision size differs according to the patient’s body size, the perfusion strategy and the surgeon’s preference. This incision is also useful for tricuspid valve and reoperative mitral/tricuspid valve operations. Right thoracotomy is also used for aortic valve operations by making an incision more medially in the 2nd or 3rd intercostal space (Figure 2B). Peripheral cannulation is usually required, but central cannulation is possible if a large incision is made. The ascending aorta is cross-clamped with a direct flexible clamp, transthoracic clamp or endoaortic balloon clamp. This incision provides

Figure 1.  Sternal incisions for upper (A) and lower (B) hemisternotomy.

Figure 2.  Intercostal incision for a right thoracotomy. Right anterolateral thoracotomy for mitral valve access (A) and right anterior thoracotomy for aortic valve access (B).

operations and for aortic valve operations if the anatomy fits. It also has some variations in the shape and size. Central aortic and venous cannulation can be achieved but peripheral cannulation is occasionally required.

Partial sternotomy is relatively simple; it does not require special setup or equipment (patient’s positioning, instruments and cannulae), and it is easy to convert to a full sternotomy if necessary. However, cosmetic merit is minimal, especially with upper hemisternotomy, and sternal division is still needed.

Right parasternal incision is a useful option for aortic and mitral valve operations. For this incision, the 3rd and 4th right costal cartilages are resected. Peripheral arterial cannulation is usually required, and venous cannulation can be achieved centrally or peripherally. This incision does not require sternal division. However, the internal mammary artery often needs to be divided, and the occurrence of instability of the anterior chest wall has been reported.

Thoracotomy

Thoracotomy is the most common minimally invasive access to the mitral valve. The mitral valve is usually well exposed through this access because it is facing the right side of the chest in its natural position.
scopic) and robotic approaches. In these approaches, the valve is accessed through even smaller incisions and holes on the right chest. Ribs are minimally spread with a soft tissue retractor, and no metal retractor is used. Surgeons do not look into the chest directly but look at the valve displayed on the screen of the thoracoscopic or robotic system. At our institution, we perform a totally thoracoscopic mitral valve operation through a 3–5 cm main incision and a couple of 5-mm ports (Figure 3A). CPB is instituted with peripheral cannulation by the use of femoral arterial perfusion and bicaval venous drain-

**Figure 3.** Incisions and cannulation in endoscopic minimally invasive valve surgery. Small thoracotomy and ports (A), internal jugular venous cannulation (B), femoral arterial and venous cannulation (C) and subclavian arterial cannulation (D).

**Figure 4.** Endoscopic visualization of the mitral valve. Prolapsing leaflet (A) and papillary muscles (B) are well visualized.

complete sternal preservation and excellent cosmesis. However, special setup and equipment (eg, double-lumen endotracheal tube, percutaneous cannulae, special clamps, minimal incision rib retractor, long-shafted surgical instruments and a thoracoscopic imaging system) are required. Other thoracotomy incisions, including a right vertical infra-axillary thoracotomy and left thoracotomy, are less commonly used.

**Endoscopic/Robotic Surgery**

More advanced MIVS includes totally endoscopic (thoracoscopic) and robotic approaches. In these approaches, the valve is accessed through even smaller incisions and holes on the right chest. Ribs are minimally spread with a soft tissue retractor, and no metal retractor is used. Surgeons do not look into the chest directly but look at the valve displayed on the screen of the thoracoscopic or robotic system. At our institution, we perform a totally thoracoscopic mitral valve operation through a 3–5 cm main incision and a couple of 5-mm ports (Figure 3A). CPB is instituted with peripheral cannulation by the use of femoral arterial perfusion and bicaval venous drain-
Surgical robotic technology has been advancing remarkably in the past decade. The commercially available surgical robotic system provides 3-dimensional imaging and fine manipulation. CPB is instituted with peripheral cannulation and the valve is approached through a small thoracotomy (2–4 cm main working port) and several 8-mm ports. The robotic approach does not reduce the incision size much, but may increase the number of small incisions compared with the totally endoscopic approach; however, a full range of motion without tremor of the robotic arms enables a surgeon to perform complex procedures more easily. The disadvantages include the high cost of the robot and its components, longer learning curve, and the huge size of the system, which does not fit in a small operating room.

Surgical scars of endoscopic minimally invasive valve surgery in a male (A) and a female (B) patient.

Results of MIVS

Many surgeons have reported their MIVS data on various different approaches and strategies, with favorable results. Several high-volume centers have presented very large series of MIVS, which are helpful to understand high-standard outcomes and potential complications of MIVS. Also, many studies have compared outcomes between MIVS and conventional valve surgery, and they provide us with important information to discuss whether avoiding a full sternotomy improves the outcome of heart valve surgery. However, there have been only a few randomized controlled studies, and most of them seem underpowered. In many observational comparative studies, the MIVS group includes patients with a lower risk profile than the conventional valve surgery group. Thus we need to be careful of potential bias remaining even after statistical adjustment. Also, publication bias may exist. Negative results and bad outcomes often remain unpublicized.

Generally, MIVS has been shown to have comparable mortality and morbidity to conventional valve surgery and to be associated with some beneficial effects of avoiding full sternotomy and some adverse effects of limited access and perfusion system. The effect of avoiding a full sternotomy on long-term survival remains poorly defined, because there have been only a few long-term comparative studies. If quality of valve surgery is impaired in MIVS (eg, inadequate size of implanted prosthesis, presence of paravalvular leak, residual or recurrent regurgitation), long-term survival may be affected. Thus, following the quality data of MIVS is very important. Most long-term comparative studies have shown that MIVS has comparable quality of surgery and long-term outcomes.

Aortic Valve Surgery

Several large studies have reported early and late outcomes of minimally invasive aortic valve surgery via an upper hemisternotomy. Tabata et al reported, in their series of 1,005 aortic valve operations via an upper hemisternotomy, that the operative mortality was 1.9% compared with a predicted mortality of their cohort of 7.5%. Their patient cohort included a significant number of elderly patients aged ≥80 years, and they demonstrated low operative mortality (1.7%) and short length of stay (8 days in median) in the subgroup of the octogenarians. Johnston et al performed a large single-center comparative study of upper hemisternotomy (n=1,193) and conventional full sternotomy (n=1,496) for aortic valve surgery. Their propensity-matched comparisons showed no difference in operative mortality, stroke, sternal complications and re-exploration for bleeding. The partial sternotomy group had shorter ventilation time (5.2 vs. 6.9 h), lower incidence of respiratory insufficiency (2.9% vs. 5.4%), less postoperative bleeding (100 vs. 250 ml), lower transfusion rate (24% vs. 34%), less pain, and shorter ICU and hospital stays. Also, the 10-year survival rate was similar in both groups (77% vs 73%). Brown et al, in their meta-analysis of studies comparing partial sternotomy and full sternotomy for aortic valve replacement (26 studies including 4 randomized controlled studies and 4,586 patients), showed no difference in operative mortality, incidences of stroke and sternal complications. Cross-clamping and CPB
times were slightly longer in the partial sternotomy group. The partial sternotomy group had shorter ventilation time by 2h, shorter ICU stay by 0.5 days, shorter hospital stay by 0.9 days, and less postoperative bleeding by 80ml.  

Right thoracotomy approach is another minimal access to the aortic valve. Several comparative studies (thoracotomy vs. conventional sternotomy) have shown that the thoracotomy group had similar mortality, shorter ICU stay and shorter hospital stay despite longer CPB and aortic cross-clamping times than the conventional group.  

Brinkman et al demonstrated no incidence of paravalvular leak or prosthesis dysfunction in either group, which may indicate that limited access did not compromise their technical quality.  

**Mitral Valve Surgery**  
Some large series presented from experienced centers have demonstrated a very low operative mortality and morbidity. In a series of 1,000 minimally invasive mitral valve operations (lower hemisternotomy was used in 75% and mitral valve repair was performed in 92%) reported by McClure et al, operative mortality was 0.8%, median hospital stay was 5 days, and 15-year survival was 79%.  

Svensson et al reported a very low operative mortality (0.19%) and high 8-year survival (86%) in their series of 2,124 minimally invasive mitral valve operations (upper hemisternotomy was used in 87% and mitral valve repair was performed in 90%).  

Seeburger et al, in their series of 1,230 minimally invasive mitral valve operations via a right thoracotomy, reported a 30-day mortality of 1.8%, stroke incidence of 2.4% and 5-year survival of 87%.  

In a recent meta-analysis of 35 studies (including 2 randomized studies) comparing outcomes of mitral valve surgery between right thoracotomy and full sternotomy, there was no difference in 30-day mortality between the 2 groups, and the thoracotomy group had less blood transfusion by 1.9 units, shorter ventilation time by 2.1h, shorter ICU stay by 0.5 days, shorter hospital stay by 1.6 days.  

Additionally, the thoracotomy group had shorter ICU stay (18.5 vs. 22.5h) and hospital stay (3 vs. 5 days) than the conventional group. They also showed that the robotic group had longer CPB and aortic cross-clamping times.  

In contemporary mitral valve surgery, mitral valve repair is the gold standard and it does require higher technical skill than mitral valve replacement. The choice of minimally invasive approach should not compromise the technical quality of mitral valve repair. McClure et al reported that 6 of 929 minimally invasive mitral valve repairs were intraoperatively converted to mitral valve replacement because of technical failure, and that 15-year freedom from mitral reoperation was 90%, with 5- and 10-year freedom rates from recurrent moderate or severe mitral regurgitation of 87% and 69%, respectively.  

Seeburger et al reviewed their 1,230 minimally invasive mitral valve operations for anterior (n=156), posterior (n=672), and bileaflet prolapse (n=402). Their repair rate was 94%, and the 5-year freedom from mitral reoperation was 96%-22%. Speziale et al randomized 140 patients with complex Barlow disease into 2 groups: direct-vision right thoracotomy group and conventional sternotomy group. They showed similar successful repair rates and freedom from moderate or severe mitral regurgitation (MR) in the mean follow-up period of 12 months.  

Suri et al, in their propensity-matched comparisons of robotic and conventional mitral valve repair for all prolapse subsets, showed no difference in residual MR rates evaluated by intra-operative and early postoperative echocardiography. On the other hand, Raanani et al compared the quality of mitral valve repair for posterior leaflet prolapse between right thoracotomy and conventional sternotomy, and showed a trend toward increased rate of recurrent moderate or severe MR (18% vs. 9%) in the thoracotomy group, although the difference was not statistically significant. They suggested that their minimally invasive skill was still on the learning curve.  

Concomitant tricuspid valve repair and Maze procedure are often performed with conventional mitral valve surgery and should not be omitted in MIVS if they are necessary. Those concomitant procedures can be performed safely with the direct-sight, endoscopic and robotic approaches.  

High-quality mitral valve surgery can be achieved with minimally invasive approaches, which seem to largely depend on each surgeon’s experience and skill in both mitral valve repair and minimally invasive techniques.  

**Advantages of MIVS**  
As mentioned earlier, MIVS has been shown to have comparable mortality to conventional valve surgery. This finding implies that avoiding a full sternotomy does not minimize surgical invasiveness enough to reduce operative mortality. However, avoiding a full sternotomy has been consistently shown to have beneficial effects such as reduced blood transfusion, ventilation time, ICU stay and hospital stay.  

Recently, Suri et al showed that robotic mitral valve repair patients returned to work earlier than conventional repair patients (33 vs. 54 days).  

Theoretically, sternal wound infection does not occur with the thoracotomy approach, which is a definite advantage of that approach. However, the partial sternotomy approach was not associated with a lower incidence of sternal wound infection in the large comparative studies.  

The advantageous effects of the minimally invasive approach on postoperative atrial fibrillation and respiratory function are controversial. Avoiding a full sternotomy may somewhat reduce postoperative pain but the issue is controversial especially for the thoracotomy approach.
Potential Drawbacks of MIVS

Most of the published studies have shown favorable results of MIVS, emphasizing its advantages. However, we need to be aware of the drawbacks of MIVS to make appropriate selection of both the patient and approach, and to avoid complications.

The possible association of the minimally invasive approach with increased stroke is an important concern. This association may be related to peripheral cannulation, aortic cross-clamping system and/or difficult de-airing. By knowing such potential causes of complications, modifying the preoperative assessment and surgical technique could reduce complications in MIVS.

Peripheral Cannulation

Most MIVS approaches require peripheral cannulation, including femoral arterial and venous access. Femoral arterial perfusion has potentially increased risks of embolization (stroke), aortic dissection and limb ischemia. Retrograde arterial perfusion may pump atherosclerotic plaque or thrombus in the aorta up to the cerebral arteries. Murzi et al, in their study of 1,280 minimally invasive mitral valve operations, showed that retrograde arterial perfusion was independently associated with a higher incidence of stroke (odds ratio 4.28, 95% CI 1.69–10.83). Grossi et al, in their study reviewing 3,180 conventional and minimally invasive valve operations, showed the same association in the elderly, but no significant association in patients aged ≤ 50 years.

Central aortic cannulation is somewhat challenging in MIVS, other than with partial sternotomy approaches, unless a large incision is made. Subclavian or axillary arterial perfusion is an alternative antegrade access. We assess atherosclerosis of the aorta, iliac and femoral arteries by contrast CT for all MIVS candidates who are 50 years or older or have atherosclerotic risks. If we find atherosclerotic lesions, mural thrombosis, severe calcification in those arteries, we cannulate the right subclavian artery with interposition of a Dacron graft. For small femoral arteries, we use interposition of the Dacron graft instead of direct cannulation to prevent vascular injury and limb ischemia.

Peripheral venous cannulation has a potential risk of venous perforation. Guide wires and cannulae need to be carefully manipulated under the guidance of transesophageal echocardiography. Preoperative CT is useful to find venous anomalies such as left superior vena cava.

Additionally, femoral cannulation has a risk of groin wound infection, hematoma or lymphocele. The incidence of groin wound complications has been reported as between 1.7% and 15%.

Aortic Cross-Clamping

In MIVS via a small right thoracotomy, a transthoracic clamp or endoaortic balloon clamp is used for aortic cross-clamping. In a subgroup analysis of the previously cited meta-analysis study, there were a trend toward increased risk of stroke in the thoracotomy patients in the endoaortic clamp group, significantly increased risk of stroke in the studies with mixed use of endoaortic and transthoracic clamps, and no difference in the stroke risk in the studies using only transthoracic clamps. On the other hand, Krapf et al showed no significant difference in major complications, including stroke, between 2 different clamp systems. Either clamp can be used by surgeons as long as they are familiar with the equipment, because each clamp has its advantages and disadvantages.

Longer CPB and Cross-Clamping Times

Most studies have shown that MIVS is associated with significantly longer CPB and cross-clamping times compared with conventional valve surgery, which is logical given the difficulty of operating with limited access. There is a learning curve, those times become shorter as the surgical team accumulates experience with MIVS, and new devices such as sutureless valves may solve this problem. However, currently, even experienced surgeons still take longer with MIVS if they perform the same procedure using different approaches. Long CPB and cross-clamping times may affect operative outcomes in high-risk patients. This potential negative effect may outweigh the advantages of avoiding a full sternotomy, which should be considered in the selection of patients for MIVS.

Conversion to Full Sternotomy

Conversion to a full sternotomy is occasionally required during MIVS. The frequency of conversion from the partial sternotomy incision has been reported as between 1.8% and 4.0%. The reasons for conversion from a partial sternotomy include bleeding, ventricular dysfunction, refractory arrhythmia and poor exposure of the valve. Conversions in the emergency situation with hemodynamic deterioration have been shown to be associated with serious mortality and morbidity, whereas conversions without hemodynamic compromise were not. The conversion rate of the right thoracotomy approach has been reported as between 1.1% and 9.1%. Volfroth et al, in their large series of 3,125 minimally invasive mitral valve operations, reported a very low conversion rate (1.1%) and a high 30-day mortality of conversion cases (23.5%). The reasons for conversion included bleeding, aortic dissection and severe pulmonary adhesion.

Such elective conversions are not likely to result in serious complications, but can be avoided with thorough preoperative assessment. Adequate patient selection, understanding the pitfalls and precautions, and meticulous technique are essential in MIVS to avoid conversions and secondary adverse results.

Patient and Approach Selections for MIVS

People may think that “minimally invasive” procedures are good options for patients who are at high risk for conventional surgery, because transcatheter valve procedures are indicated for such patients. However, high-risk patients may not be good candidates for MIVS because they are likely to be adversely affected by the longer CPB and cross-clamping times of MIVS.

Patient selection criteria depend on each surgeon’s (surgical team) experience and skill. Some highly experienced centers routinely choose MIVS even for the most complex valve disease, which is not an appropriate strategy in less experienced centers. Currently, we exclude high-risk patients and complex valve pathology from MIVS candidates. Our other contraindications for MIVS include patients requiring concomitant pro-
cedures such as coronary and aortic surgery, severe chest wall deformity and diseased ascending aorta (calcification, mural thrombus or dilatation). Additionally, severe pulmonary dysfunction that cannot tolerate 1-lung ventilation and previous right thoracotomy are relative contraindications for MIVS via a right thoracotomy.

The approach of MIVS should be selected based on the target valve, patient’s anatomy, perfusion strategy and the surgeons’ training. Above all, surgeons should use the approach that they are comfortable with. Cannulation sites should be selected based on vascular anatomy, size and the presence and extent of atherosclerotic disease.

Team Approach in MIVS

The importance of a team approach needs to be emphasized more for MIVS than for conventional valve surgery. MIVS has a more complex operative setup and process flow, so not only the surgeons but also all other staff in the operating room must be well trained and familiar with MIVS. For example, the role of intraoperative transesophageal echocardiography is more extensive in MIVS than in conventional valve surgery. In addition to regular assessment of valvular and ventricular function, it is required to track wires and cannulae, monitor left ventricular volume, confirm adequate aortic cross-clamping and check for residual air in the heart because manual assessment and manipulation are not possible with the limited access. Additionally, optimal postoperative management with aggressive promotion of early ambulation is essential to maximize the benefits of MIVS: early discharge and fast recovery, which can be achieved only when all staffs caring for MIVS patients understand the benefits and purpose of MIVS.

Conclusions

The level of evidence for the effect of the minimally invasive approach on outcomes of heart valve surgery may not be high enough to make definitive conclusions, but MIVS has been consistently shown to contribute to reduced blood transfusion and faster recovery without compromising the quality of surgery. On the other hand, there are several drawbacks of MIVS that can potentially cause serious complications. Careful selection of the patient, approach and perfusion strategy based on thorough preoperative assessment and each surgical team’s experience are necessary to perform MIVS safely. MIVS should be performed by an experienced surgeon and surgical team, because there is a significant learning curve. Under these conditions, the minimally invasive approach is likely to improve outcomes of heart valve surgery.

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