〈Review〉

Minimally invasive cardiac surgery via a right mini-thoracotomy

Masahiko KUINOSE, Tatsuya WATANABE, Kotone TSUJIMOTO,
Kensuke KONDO, Ryutaro ISODA, Noriyuki TOKUNAGA, Atsuhisa ISHIDA,
Ichiro MORITA, Hideo YOSHIDA, Tomoki YAMATSUJI

Department of General Surgery, Kawasaki Medical School

ABSTRACT Minimally invasive surgery, which has become very active outside the cardiovascular field, has recently come to the fore in this area. Then, procedures such as off-pump coronary artery bypass grafts without extracorporeal circulation and stent grafts for treating aortic aneurysms have been frequently performed.

In cardiac surgery, as in other surgical fields, more and more surgeries that are less and less invasive have been introduced in recent years. Off-pump coronary artery bypass grafting has contributed to the development of these less invasive surgeries. For example, cardiac surgery utilizing a partial sternotomy was introduced as a way to better access the surgical location. However, minimally invasive cardiac surgery (MICS) through a right mini-thoracotomy, a port-access cardiac surgery, is said to be trending recently because it avoids a sternotomy and has less bleeding and wound infection. All of these factors not only promote early recovery, but are also expected to have a positive impact on early discharge and the health care economy.

With surgeons and hospitals accumulating experience, MICS is being applied to more complex lesions and has begun to be used to treat the aortic valve in addition to the mitral valve. Off-the-job training and team building are also key factors for implementing a successful program. This type of port-access cardiac surgery is already beginning to be developed into a robotically assisted heart surgery by various facilities around the world.

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INTRODUCTION

Currently, "open heart surgery" to treat valves or tumors in the heart or to correct an irregular pulse requires a median sternotomy, which necessitates extracorporeal circulation[1, 2]. If the heart can be accessed without performing a median sternotomy,

Corresponding author
Masahiko Kuinose
Department of General Surgery, Kawasaki Medical School, Kawasaki Medical School General Medical Center, 2-6-1 Nakasange, Kita-ku, Okayama, 700-8505, Japan
Phone : 81 86 225 2111
Fax : 81 86 232 8343
E-mail: kuinose@med.kawasaki-m.ac.jp

wounds recover more quickly and the risk of complications such as meningitis becomes lower, thus shortening the time required for a full recovery. In cardiac surgery, as in other surgical fields, more and more surgeries that are less and less invasive have been introduced in recent years. Off-pump coronary artery bypass grafting has contributed to the development of these less invasive surgeries. For example, cardiac surgery utilizing a partial sternotomy was introduced as a way to better access the surgical location. However, minimally invasive cardiac surgery (MICS)[3-5] through a right mini-thoracotomy, a port-access cardiac surgery, is said to be trending recently because it avoids a sternotomy and has less bleeding and wound infection. Our surgical group first began performing minimally invasive cardiac surgery (MICS) through a right mini-thoracotomy on patients with an atrial septal defect (ASD)[6]. We have since moved on treating the mitral valve, tricuspid valve, aortic valve and even for atrial fibrillation using the maze procedure[7-10].

Open surgery has been giving way to more 3D endoscopic surgeries in recent years to treat the mitral valve, which is more easily accessible from the right[2]. Such procedures have improved over time and recent incisions have been as small as 5 to 6 cm. One factor contributing to the improvement has been stable mitral valve annuloplasty for treating mitral insufficiency, which affects a majority of patients. The disadvantages of MICS are potential cardiac arrests and prolonged extracorporeal circulation time, and so is more suitable for simpler valvular repairs and replacements.

We have been improving surgical tools and equipment as well as our methods, and thus have actively expanded our application of MICS as we acquire more experience and knowledge. This prominent surgical method can be expected to be applied to further diseases and conditions in the future. Here, we will introduce the advantages as well as the disadvantages that we have observed and experienced from our cases.

1. MICS criteria and applicable diseases

The aortic valve, mitral valve, tricuspid valve, atrial septum, left atrium and left ventricle are all accessible by a right mini-thoracotomy, with each having slightly different access positions and angles. In most cases MICS is performed on a single valve at a time because the limited surgical visual field and access angles make accessing multiple valves or lesions difficult. However, multi-valve surgery is occasionally required when mitral valve disease accompanies mitral regurgitation or atrial fibrillation.

We performed over 380 cases of MICS for 15 years. Table 1 shows the application of MICSs. The following conditions are considered dangerous and preclude a MICS right mini-thoracotomy: accompanying coronary artery disease, a dilated and/or calcified ascending aorta, poor femoral or axillary arterial condition (making extracorporeal circulation dangerous), a right pleural adhesion, low left lung function (making one-lung ventilation risky), or a deformed vena cava. Thoracic abdominal CTs (both non-contrast and enhanced) are required preoperatively for all cases to evaluate the whole body for the conditions listed above. The CTs are also important help understand the depth and appropriate angle based on the valve(s) to be treated and their position between the intercostal space.

Table 1. Indication criteria for MICSs

The ascending aorta and coronary arteries are not damaged.
Cardiac function is fair.
The arteries such as femoral artery have no calsification, stenosis and atheroscleros.
The lungs have no desease with inflamation or adhesion.
The patient is resistible to one lung ventilation.
The superior and inferior vena cava are opening into right atrium.

2. How to establish extracorporeal circulation in MICS

In principle, extracorporeal circulation should be established using peripheral veins and arteries. Direct cannulation from the surgical field in a right mini-thoracotomy is done on occasion, but inserting a cannula from the port limits the surgical view. The catheter gauge is based on the patient's body weight. Narrow arteries, occurring especially in some younger female patients, can necessitate extra-ordinary measures, such as using both femoral arties or suturing an artificial graft/tube onto the end of the artery.

Another concern affecting MICS efficiency and safety is proper venous drainage. Obstructed drainage can impair the surgical visual field, especially in MICS. Therefore, when inserting the catheter into peripheral veins, such as the femoral and jugular veins close to the heart, proper cannula drainage placement is crucial. The catheter should be carefully placed using transesophageal echocardiography (TEE) or a fluoroscope. Vacuum-assisted venous drainage is also useful, but care should be taken to carefully follow the guidelines because of the negative pressure created inside of the venous reservoir (Table 2).

There are some additional considerations when inserting and placing a catheter in a peripheral artery or vein. Some possible complications are arterial damage at the duct opening, retrograde aortic dissection, peripheral ischemia, or embolism. Thus, to make sure for safety that there is no abdominal aortic aneurysm or arteriosclerotic lesion, the wire guide should be double-checked while being inserted, and the size of the catheter should be reconfirmed. All the while, careful manipulation during insertion under the guidance of TEE or a fluoroscope is critical.

While connecting the extracorporeal circulation, prepare to occlude the ascending aorta after confirming proper venous drainage and blood flow. There are facilities outside of Japan that use a balloon catheter for occlusion. In that method, insert the balloon along the side of the blood supply catheter in the femoral artery and advance it to the ascending aorta, then inflate the balloon to block the aorta and inject the cardioplegic solution from the tip of the catheter[1]. Unfortunately, this type of balloon catheter is currently not approved for usage in Japan due to concerns that it could tear or sever the ascending aorta, so this technique is unavailable at our institution.

Instead of a balloon catheter, we utilize two kinds of clamps, Chitwood clamps and Cosgrove flex clamps, to occlude the artery. Chitwood clamps are used more often, and we insert them from a different intercostal space than the one for the main port to attain a satisfactory surgical view. Next, inject the cardioplegic solution antegrade from the cannula in the ascending aorta. While injecting, confirm by TEE that the artery has been completely occluded and that the aortic valve is closed as well.

3. Mitral valve MICS

1) Anesthesia and body positioning

Under general anesthesia, prepare for one lung ventilation (blocking the right lung) using a double lumen tube. Next, use a wire guide in the sheath put in the right internal jugular vein during the angiography and advance it to the superior vena

Table 2. Blood flow management in MICS

Mitral valve	Blood supply tube/arterial cannula is inserted into right femoral artery. Blood removal tube/vent catheter from SVC is inserted into right internaljugular vein. Blood removal tube from IVC is inserted into right internaljugular vein.
Aortic valve	Blood supply tube is inserted into right femoral artery. Blood removal tube is inserted into right femoral vein (The tip of tube is located at SVC orfice.).

SVC, superior vena cava; IVC,inferior vena cava

cava (SVC), then to the right atrium (RA) and to the inferior vena casa (IVC). Leave 3 cm of the wire guide out of the skin, affix it there and prepare for the insertion of venous drainage. The patient is laid in semi-left lateral recumbent position with a pillow from the right shoulder to the hip. The right arm should be affixed to the side of the body with a pillow underneath it. The surgical field should be prepared up to the posterior axillary line.

2) Accessing the surgical site

Access from the fourth intercostal space for most cases. The skin incision for male patients is usually 5 cm from the outer side of the papilla. For female patients the incision starts along the bottom line of the breast and goes to the outer line for cosmetic reasons, giving a bigger incision than the male patients. Then, advance into the fourth intercostal space after dividing the muscles. Most of the bleeding comes from the thoracic wall, so incise the muscles of the thoracic wall with ultrasonic scissors to arrest the bleeding. The incision through the intercostal muscle should be twice as long as the skin incision so that the ribs will not be under excess burden. Next, deflate the right lung to access the right pericardium. After locating the phrenic nerve, make a 2 cm incision on the anterior side. Incise close to the diaphragm and pull the posterior pericardium closer to acquire an adequate surgical view.

Normally the posterior pericardium is lifted with three retraction sutures but the suture closest to the diaphragm can have the effect of pushing the diaphragm down, so pull the suture as inferiorly as possible and pull down the intercostal space, then fix it onto the skin. The second suture is fixed at the level of the right pulmonary vein and the third one is at the reflection of pericardial SVC. The suture strings go through the intercostal space and are fixed onto the skin, fix them as close to the posterior side as possible to avoid interference later. A considerably good surgical view should be acquired when the lifting is done along with the one lung ventilation. Extra care is required to avoid excessive lifting of the pericardium which can be damaged as well as causing ventilatory failure of the left lung. Alternatively, one or two suture strings attached to the anterior side of the pericardium can be lifted but they should only be gently pulled out with a clamp from the main port. Confirm the blood has stanched and then perform a systemic heparinization. Set a wound protector on the main port and make sure that the device and the suture strings aren't touching the skin.

3) Occluding the ascending artery, venting the left atrium and de-airing

Start extracorporeal circulation and confirm the complete and smooth venous and aortic perfusion. Then prepare for the ascending arterial occlusion. Lower the blood pressure and dissect the posterior side of the ascending artery bluntly at the upper edge of the right pulmonary artery. It is common to use an occlusion clamp on the transverse sinus by the bottom edge of the pulmonary artery, but then the cannula site for injecting the cardioplegic solution is limited to only near the artery root and there is a higher possibility of having difficulty stanching the blood later in the procedure. Also, the left atrial auricle may be damaged by the occlusion clamp. Therefore, our technique is to insert the occlusion clamp from the upper edge of the right pulmonary artery towards the lesser curvature of the aortic arch.

Insert the clamp from either the first or the top of the second intercostal space through the main port and pay extra attention to the curve of the clamp so that it does not block the surgical manipulation.

Create a separate port to insert a left atrial vent through a route that does not block the surgical visual field. After occluding the ascending artery, start vent aspiration and completely withdraw the blood from the left atrium. The tip of the vent should be placed at the opening of the left superior pulmonary vein. Also, carbon dioxide should be insufflated continuously into the chest cavity from this vent port. Until the closure of the left atrium, carbon dioxide is insufflated at 2 L/min and once the closure procedure starts, increase the volume to 10 L/min to avoid an air embolism.

The following technique to remove air from the chest cavity during MICS might be considered controversial, but if the steps are performed carefully, this air removal is actually easier than performing a median sternotomy because the incision area of the left atrium will be the highest in the right mini-thoracotomy MICS. The procedure is: 1) close the left atrium while insufflating with carbon dioxide, and 2) simultaneously loosen the vent and fill the left ventricle with blood and then fill the left atrium.

4) Key points in mitral valve repair

Endoscopes work well for mitral valve repair MICS. We have recently introduced a 3D HD (high definition) endoscope that enables the mitral valve structure to be shown in 3D and has subsequently improved the quality of our repair surgeries. 3D endoscopy is common in robotically assisted surgeries, but surgery using a 3D endoscope alone is uncommon. The surgery requires not only the endoscope itself, but also a 3D display and special polarized glasses to view the display. The viewing angles can be restricted by the glasses, but the 3D images are so beneficial that the learning curve to acquire endoscopic surgical skills can actually be shortened.

Special tools are required to operate on the mitral valve because of the depth of the surgical site. Skilled manipulation of the tools is also important. The shaft of the tool is long, so that even a slight movement of the surgeon's hand becomes a much bigger movement at the tip of the tool. Delicate manipulation is often required, so being able see enlarged images on a monitor has a positive effect on surgery. Fingers aren't long enough to reach and ligate so a special knot pusher is used. There are many ligations to be done, so surgeons need to be skillful at using the knot pusher.

Also, unlike other common cardiac surgeries, there is no surgical view expansion by surgical assistants, so the surgeon must endeavor to have a clear surgical view in the left atrium. If necessary, add supplementary retraction sutures and spare no effort that will help to expand the surgical view.

4. Tricuspid valve and atrial septal defect MICS

Beforethe right atrium is incised, it is necessary to occlude the SVC and IVC because the air tracts through the venous line. The SVC is ligated with a thick string and the IVC often does not require an occlusion or closure when the venous drainage duct is placed near the diaphragm because the IVC closes itself up naturally from the negative pressure.

The tricuspid valve is near the sternum and performing a right mini-thoracotomy MICS may be difficult because the surgical vision is not good unless the incision is made closer to the median than in other procedures. This surgery is often performed at the same time as mitral valve surgery, with the surgical field reaching the fourth intercostal space, so moving the incision 2-3 cm towards the median is a good adjustment. Treating an ASDrequires a surgical field looking down from the sternum, so access should be as close to the sternum as possible. If the patient has cosmetic concerns, then incise from just beneath the breast and go through the fourth intercostal space. By utilizing an endoscope, a poor surgical visual field can be improved for surgeries treating both the tricuspid valve and ASD.

5. Treating atrial fibrillation

Some cases requiring mitral valve surgery have accompanying atrial fibrillation, and the maze surgery is performed simultaneously. To improve the post-operative quality of life for patients, a surgical procedure similar to the maze surgery that is performed under a median sternotomy needs to be established. Therefore, high frequency cautery, in this case a bipolar clamp, is among the devices used for the median incision because it can be used from a right mini-thoracotomy port and can completely isolate all layers of tissue.

During usage, the tip should have some freedom so that it can be inserted from the port and be used in multiple directions. Form an isolation line as if extending the incision line of the left and right atriums, and in areas where the clamp cannot be used, use coagulation or a pen-type bipolar device. Creating a firm isolation line, even though it requires extra effort, is important when operating on the valve ring. Then close the left atrial auricle from the inner side of the left atrium.

6. Aortic valve replacement

To administer anesthesia, left lung ventilation is required the same as in mitral valve surgery. Only one venous drainage duct is needed and should already be inserted from the femoral vein to the SVC. Unlike mitral valve surgery, the incision to access the surgical site is often on the right edge of the sternum in the third intercostal space.

Before surgery, confirm the location of the ascending artery on a CT, it should be located close to the right of the median. Also confirm that the level of the aortic valve is not too far from the fourth intercostal space. Perform the thoracotomy through the third intercostal space. Different from a lateral thoracotomy, the intercostal space might not open wide enough with rib spreader because of the sternocostal joints. After the roughly 6 cm skin incision is made, isolate the right internal thoracic artery and vein located on the median side of the incision to avoid damaging them. Isolate the sternocostal muscle on the lateral side of the sternum and isolate the intercostal muscle within its accessible range.

Incise the pericardium and lift it up in a direction where the ascending artery becomes close to the main port. In this aortic valve surgery, an endoscope isn't used and direct vision is used instead. Once extracorporeal circulation is started and under negative pressure, isolate the ascending artery and let it work well. Insert the occlusion clamp from the first or second intercostal space. By occluding the ascending artery as distally as possible, it creates more workspace and thus gives more options when selecting the most appropriate place to incise and suture the artery.

Next, incise the ascending artery and confirm the aortic valve and the coronary artery. Assistance from supporting surgeons does little to develop the surgical field view, so the surgeon needs to create the surgical view by lifting the aortic arterial wall little by little. Place the suture strings onto three points of the commissure and lift to give a better surgical view. From this point, the procedure is the same as an ordinary surgery. Extra attention is necessary when closing the incision on the aorta. Stanching the bleeding where the aorta is sutured after releasing the aortic occlusion is expected to be very difficult, especially the side of the pulmonary artery. Furthermore, after the extracorporeal circulation is stopped, the right atrium and the ventricle can obscure the incision line so that it cannot be seen. Therefore, it is especially important to stanch the bleeding completely during extracorporeal circulation instead of trying to stanch by pressuring after protamine reversal.

7. Application to other surgeries (heart tumor, removal of a foreign object in the cardiac cavity, left ventricular pseudoaneurysm, re-operation after a median sternotomy)

A right mini-thoracotomy MICS is particularly useful for mitral valve re-operation after a median sternotomy in which damage could be expected from re-incising the sternum[11]. For such a case, perform MICS for the mitral valve and start extracorporeal circulation and if there is no failure in aortic closure, induce hypothermia to cool the body core down to about 28℃. The only necessary isolation is on the right of the left atrium and when/if atrial fibrillation occurs, incise the left atrium to develop the surgical view. This is applicable for both repair and valve replacement. However, do not pull the tissues that are near the aortic valve of the mitral valve ring too much, otherwise an aortic regurgitation can occur. Therefore, with help from the perfusionist, adjust the circulation volume to assure the surgical view. This surgical method does not require the isolation of a coronary bypass graft and has little danger of damage.

One rare case we hadexperienced was when a pseudoaneurysm formed on the suture of the epicardium closure patch which was used to treat a rupture in the base area near the atrium and ventricle due to myocardial infarction. In this re-operation, too, patch closure from the inside of the cardiac cavity was possible while observing the inside of the left ventricle from the left atrium to the mitral valve using an endoscope. The fact that a right mini-thoracotomy can be applied to a case as specialized as the one above is a sign of its flexibility in application.

8. Pitfalls of MICS

MICS has advantages but also has peculiar pitfalls as shown in Table 3, which can lead to major complications, so full attention is needed. As a team, form a surgical plan with the anesthesiologist, perfusionist, and nurses who prepare the medical tools and devices so that the surgery will be carried out safely.

DISCUSSION

Minimally invasive cardiac surgery itself is not new. More than thirty years ago, right thoracotomies were tried to treatASD in female children and adults at multiple facilities, and in some places the method became the standard procedure. However, the thoracotomy tended to be large and provided no advantages to patients as well as creating problems like deformed breasts, so the surgery gradually shifted to a partial sternal incision. Even now this partial sternal incision is less invasive than a sternal thoracotomy. MICS is chosen for surgeries such as aortic valve replacement or mitral valve surgery and is selected based on each individual case.

The technique pioneered by Carpentier *et al*. in 1996 can be said to be the model of current MICS. Carpentier *et al*. reported on an endoscopic mitral valve repair with atrial fibrillation under a right thoracotomy[12]. In 1997, Chitwood *et al*. reported on a mitral valve surgery under cardiac arrest by direct vision, and two days later a video-assisted mitral valve replacement was perfomed[13].

Mohr *et al*. performed 129 mitral valve MICS from 1996 to 1998 and then divided them into two groups, earlier stage and later stage, and

Table3. Pitfalls of MICS

Pitfall	countermeasures
Damage of aorta or vena cava due to tubes	Detamination using US or X-ray examination
Incomplete shutting off of ascending aorta	Cinfiramtion and carefull maneuva
Air embolisms	Flashing with CO_2 gas
Incomplete tie with a knot pusher	Cinfiramtion and carefull maneuva
Unexpected bloodloss	Carefull hemostasis maneuva
Hypoxia	Temporaly ventilation with both lungs
Pneumothorax	Confiramation and lavage

examined the results[14]. Surprisingly, he conducted the surgeries with 3D video assistance from the initial stage and he later introduced a voice-operated endoscope, allowing him to perform the surgery solo. His results showed that artificial valve replacement was more frequently required to treat mitral valve regurgitation during the earlier stage of his surgeries. However, in his later surgeries, he was more often able to repair the mitral valve. Mohr's operation length, extracorporeal time and aortic occlusion time were all shortened during the later stage. Additionally, the number of bleeding and respiratory complications went down, and the mortality rate decreased from 8.1% to 3.0%.

Unlike in traditional surgeries, MICS has unproven elements, so a certain threshold number of surgeries needs to be reached to have stable results. The previously cited Mohr *et al*. performed 1,536 mitral valve MICS between 1999 and 2007, and the mitral valve repair was successful in 1,339 cases (87.2%). Only four of those cases required a changeover to a median incision during surgery. Moreover, 351 procedures to treat atrial fibrillation (26.2%) and 80 cases of tricuspid surgery (6.0%) were done simultaneously. The 30-day mortality rate was 2.4%[8].

Modi *et al*. also reported on 1,178 MICS in 2009. Successful repair was completed in 79.9% of the total cases, 22.5% of the total surgeries also treated atrial fibrillation and 5.4% included tricuspid surgery. They reported that operative deaths were related to factors such as age, diabetes, atrial fibrillation, and preoperative heart failure[15].

Here in Japan, Yozu *et al*. reported on MICS for the first time in 2001, and 6 out of 34 cases were mitral valve right thoracotomy MICS[16]. As the first author of this review, my own first MICS was a partial sternal incision in 1998[6] and in 2003 I first performed a mitral valve replacement under a right thoracotomy for a coronary artery bypass[7]. My personal experience with a right mini-thoracotomy MICS was that I first started on ASD, then shifted to mitral valve surgeries, then after performing more than 30 right mini-thoracotomy MICS, I adopted my current technique for aortic valve replacement, gradually raising the difficulty level[9]

Compared to a conventional median sternotomy, aortic valve MICS has significantly extended aortic occlusion and extracorporeal circulation times, but the overall length of the operation was not different. The percentage of the cases that required blood transfusion was low, postoperative artificial respiration duration was shortened, ICU stay and hospital admission days after surgery were also shortened. These improvements show the advantages of a right mini-thoracotomy MICS as comparison of intraoperative (Table 4) or postoperative (Table 5) data[8]. Because of our experience with younger patients with a well-preserved cardiac function, we consider a right

Table 4. Comparison of Port-Access and Conventional Standard Approach in aortic valve replacement--- Intraoperative data ---[8]

Intraoperative Data	**PAVR (n=37)**	**CAVR (n=107)**	**P value**
Operative time (min)	249 ± 43	241 ± 53	0.36
Cross-clamp time (min)	97 ± 23	83 ± 24	< 0.01
CPB time (min)	139 ± 28	113 ± 34	< 0.01
Prosthetic valve type			
Mechanical	17	16	< 0.01
Bioprosthetic	20	91	< 0.01
Prosthetic valve size	22.2 ± 1.9	20.6 ± 1.7	< 0.01

CPB, cardiopulmonary bypass; PAVR, port-access aortic valve replacement; CAVR, conventional aortic valve replacement

Table 5. Comparison of Port-Access and Conventional Standard Approach in aortic valve replacement--- Postoperative data ---[8]

Postoperative Data			
	PAVR (n=37)	CAVR (n=107)	P value
Reoperation for bleeding	0	1	0.57
Reoperation for valve dysfunction	0	1	0.57
Reoperation for other cardiac factors	0	3	0.71
Neurologic events	0	0	−
Myocardial infarction	0	1	0.57
Surgical site infection	1	2	0.72
Death	1	2	0.71
Blood transfusion	11	90	< 0.01
Postoperative ventilation time (h)	3.4 ± 1.9	8.2 ± 16.3	< 0.01
ICU stay (day)	1.2 ± 0.6	2.5 ± 1.7	< 0.01
Postoperative hospital stay (day)	11.1 ± 4.3	19.7 ± 7.8	< 0.01

ICU, intensive care unit

mini-thoracotomy MICS to be beneficial for patients who are expecting a quick return back to daily life, especially for patients with occupations that require hard labor. Other reports have also similarly shown a prolonged extracorporeal time, with a shorter hospital admission, less blood transfusion and fewer complications[17].

A few right mini-thoracotomy MICS cases have included some special and difficult instances such as multiple valve disease[18] and the previously stated repair of a left ventricular pseudoaneurysm[19]. Extraordinary MICS cases require a surgeon to have already mastered advanced skills and have a deep understanding of the surgical procedure due to the surgery basically being performed through a small wound. There is a definite learning curve in which surgeons will acquire these skills as their experience rises. It is highly recommended for surgeons to start their learning process with easier cases and then gradually move on to more difficult ones. This will enhance both the effectiveness and safety of the technique, and eventually a right mini-thoracotomy MICS can effectively be applied to cases such as re-surgery[20-22].

As the first author of this review, I, myself, have experienced some specific complications such as bleeding, respiratory failure, and lower limb ischemia cause by cannulation. With each complication, I clarify what can be improved in order to advance forward in future surgeries. I feel that I am still in the middle of the learning curve.

There are some reports about performing MICS without an endoscope and yet attaining good outcomes[23], but it can be said that an endoscope is an important tool that can supplement the poor surgical view during MICS. The 3D HD system that I use is helpful, especially for beginners, and utilizing it can shorten the length of the learning curve just like in robotic assisted surgery[24]. Using an endoscope is also useful for educating specialists because it allows all of the learners to see the surgical field and the techniques that are usually impossible to see during a conventional mitral valve surgery except by the performing surgeon. Video evaluating the valve after the repair can be shared with everyone and is beneficial for the learners[25].

There are also some opinions that MICS with an endoscopy is close to being robotic assisted surgery. Currently, some facilities outside of Japan conduct mitral valve surgery using a robot[26-28], but it is not common yet. One reason is that ligation during the valve repair could take too long. At the level of technology now, a delicate resection using the robot's arms is possible, but a complicated reconstruction, along with cardiac surgery time restrictions, could be too challenging. Therefore, most institutions have not been using a robot for this kind of surgery very much yet. If some new device appears in the field and solves the current problems, then robotic assisted surgery could be introduced soon after.

MICS which require an endoscope or a special long tool seem to be the work of a surgeon by themself, but they actually need support from various professionals. There are even more reasons for MICS to be considered "team medical care" than other common cardiac surgeries. The entire team including the anesthesiologist, perfusionist, operating room nurses, ICU nurses and nurses in the hospital wards are vital for a successful surgery. Everyone needs to understand MICS well and clarify their role in the process. Forming a good team and making sure everyone on that team shares a common goal is vital to conducting an effective and safe MICS.

Perioperative water management has a potent influence on both the postoperative course and complications. Bioelectrical impedance analysis (BIA) is a noninvasive means to measure body compositions including water, muscle and fat. Previously we have applied BIA as a way to measure water behavior in animal models[29]. Using BIA, we are now trying to improve perioperative water management of cardiac surgery by analyzing perioperative water behavior. We will clarify the clinical benefit and lower invasiveness of MICS using BIA as novel predictive markers for perioperative risk in cardiac surgery in the near future.

Generally, the easier the operation is, the safer it is. MICS is used for some complicated and elaborate procedures, but the techniques are very similar to those used in a median sternotomy and there are not significantly more procedures comparatively. Once the techniques are mastered, it is easy to understand that what is required is not unreasonably complicated or elaborate, and as a result, the level of safety should improve. There is always more room for improvement in a field such as MICS, and we would like to contribute to the development of MICS using our passion for creativity and simultaneously simplify the technique and procedures to improve both safety and effectiveness[30]. All of these factors not only promote early recovery, but are also expected to have a positive impact on early discharge and the health care economy.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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