Precautions During Extracorporeal Circulation in MICS

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In the fiscal year 2018, minimally invasive cardiac valve surgery was newly covered by insurance. [1] As a result, the number of minimally invasive cardiac surgery (MICS) cases, which preserve the sternum through a right mini-thoracotomy, is expected to increase. However, because it requires technically advanced maneuvers and necessitates establishing a well-organized surgical team, the hurdles to making MICS a standard procedure are by no means low. For MICS to be performed more widely and safely in the future, it is necessary to raise the capability of the entire surgical team, including not only the surgeon's skill, but also that of the anesthesiologist and perfusionists.

MICS is known to have advantages such as early recovery and reduced blood transfusion volume, in addition to the cosmetic benefits of small incisions. On the other hand, there are also pitfalls, many of which are related to extracorporeal circulation under special environments and conditions [2].

One example is that MICS uses the femoral artery and vein for extracorporeal circulation, which differs from open-chest surgery and extracorporeal circulation methods, requiring caution. JaSECT alerts perfusionists newly engaged in MICS to the extracorporeal circulation methods used in MICS. This statement is not intended for facilities that already perform safe extracorporeal circulation, but rather for facilities that are newly starting MICS, perfusionists who have not received sufficient training in extracorporeal circulation, and perfusionists who wish to review their facility's extracorporeal circulation methods, considering this statement.

1. Arterial Perfusion

Typically, in MICS, peripheral vascular cannulation is employed, so arterial cannulas of 20 Fr or smaller are often used. Consequently, arterial line pressure may exceed 250 mmHg, and pre-oxygenator pressure may exceed 350 mmHg. A report on elevated oxygenator pressures during cardiovascular surgery using an artificial heart-lung machine states: “Abnormal oxygenator pressure increases should be judged using clinical arterial line resistance as the baseline value, with twice that value as a guideline. When it is unavoidable to judge abnormal increases in pre-oxygenator pressure based solely on the absolute value of pre-oxygenator pressure, a value of 400 mmHg or higher is considered appropriate, provided the circuit connections are appropriate [3]. Therefore, to monitor oxygenator pressure increases, it is strongly recommended to install an arterial line pressure gauge between the arterial pump and the oxygenator for continuous monitoring [4], defining an abnormal pressure increase as

twice the normal pressure or higher.
Additionally, when the femoral artery is narrow and requires a smaller arterial cannula, ensuring adequate perfusion may become difficult. In such caes, after discussion with the surgical team, adding an additional arterial cannula and monitoring for lower limb ischemia using NIRS or similar methods is recommended [5,6]. If signs of lower limb ischemia are observed, consider distal perfusion to the arterial side periphery [7]. Retrograde perfusion via the femoral artery has been reported to increase the risk of cerebral infarction compared to antegrade blood delivery [8]. If the preoperative evaluation of vascular condition is poor, the team should also consider antegrade perfusion via the axillary or subclavian artery.

2. Venous Drainage
In MICS, single venous access via the femoral vein (including dual-stage cannulas) or dual venous access using the internal jugular vein or similar sites is selected. Cannulas are 28 Fr or smaller, with relatively narrow yet long lengths, resulting in comparatively high-pressure loss through the cannula. Therefore, methods such as direct drainage using centrifugal pumps or roller pumps, or vacuum-assisted venous drainage (VAVD) are frequently employed.
At the institutions that contributed to this statement, cannulation is performed while confirming proper cannula placement using fluoroscopy or transesophageal echocardiography (TEE) [9,10].

1) When using VAVD
When using VAVD, high negative pressure exceeding -60 mmHg may be applied. If adequate drainage volume cannot be achieved under VAVD (cannula "sucking" is observed) [11], inform the surgeon as the cannula placement may mispositioned. Furthermore, the reservoir used must be capable of withstanding negative pressures of at least -100 mmHg. Where possible, it is recommended to use reservoirs capable of withstanding negative pressures of -200 mmHg or more, providing a safety factor of 2 or higher. If manufacturer specifications are unavailable, prior verification is mandatory. Facilities contributing to this statement employ measures such as initiating VAVD only after sufficient blood return cannot be maintained via gravity drainage or setting the upper pressure limit based on the correlation between suction pressure and venous return volume.
Furthermore, when performing VAVD, it is essential to comply with usage precautions and warnings issued by JaSECT, The Japan Association for Clinical Engineers, The Japanese Association for Thoracic Surgery, The Japanese Society for Cardiovascular Surgery, and The Japanese Society for Artificial Organs. Perfusionists performing extracorporeal circulation for MICS must be fully capable of operating VAVD. Furthermore, it is strongly recommended to

consider alternative methods in case of medical gas suction failure, such as implementing backup suction devices [12], autotransfusion systems, or suction using roller pumps. Institutions collaborating on this statement have implemented measures such as confirming the venous return volume (delivered blood volume) under gravity drainage before initiating VAVD.

2) Closed-system, mini-circuit, etc., using a pump-assisted drainage

When performing venous drainage using a roller pump, we strongly recommend monitoring the venous drainage circuit pressure and confirming the status of drainage to avoid complications caused by excessive negative pressure. When performing venous drainage using a centrifugal pump, we also recommend monitoring the venous drainage circuit pressure to monitor the status of drainage. Consider installing bubble traps on the venous drainage side to prevent air bubbles.

3. Centrifugal Pumps

Centrifugal pumps used for cardiopulmonary bypass are generally designed to ensure a blood flow rate of 7 L/min or more and generate a discharge pressure of 500 mmHg or higher. In MICS, the negative pressure from VAVD and elevated arterial line pressure often require a relatively higher discharge pressure than usual. Therefore, attention must be paid to the upper limit of pump revolutions (RPM) of the centrifugal pump. It is recommended to review the pressure-flow characteristics of the centrifugal pump to be used during the cardiopulmonary bypass planning phase [13], and to confirm the target perfusion rate and required RPM in advance. In particular, understand the performance characteristics of the centrifugal pump being used, as some pumps exhibit a reduction in discharge pressure when blood flow rate increases, even at the same RPM. Caution is required when changing the negative pressure of VAVD, as the blood flow rate may fluctuate. Additionally, when initiating VAVD at the start of bypass, increase the centrifugal pump speed in advance, considering reservoir pressure and blood pressure, before releasing clamps or occluders.

4. Hemoconcentration and Ultrafiltration

Typically, medical components used in cardiopulmonary bypass circuits have pressure ratings of 1,000 mmHg or 760 mmHg (1 atm). In contrast, most hemoconcentration circuits, dialysis membranes, and filters have pressure ratings of 500 mmHg. For cardiopulmonary bypass in MICS, arterial pressure may exceed 400 mmHg. Therefore, when incorporating hemoconcentrators or ultrafiltration devices into an the bypass circuit, verify their pressure tolerance and exercise extreme caution in their placement. Furthermore, when using VAVD, significant negative pressure is applied inside the reservoir. Thus, attention must be paid to

circuit configuration, ultrafiltration circuit pressure, and reduced ultrafiltration efficiency due to decreased transmembrane pressure gradient [14]. Institutions collaborating on this statement incorporate a one-way valve into the waste fluid line to prevent waste fluid drawback from outside the hollow fiber membrane (waste fluid side) into the blood compartment.

5. Shunt lines and Blood Sampling lines

Due to the potential for significant negative pressure in the reservoir, caution must be exercised against air being drawn into the oxygenator or cardioplegia circuit when opening clamps on the shunt lines for air removal, sampling lines for blood gas or coagulation assessment, or blood lines for myocardial protection. Particularly with the oxygenator, negative pressure in the reservoir may draw air into the hollow fiber membrane [15]. Therefore, always maintain positive pressure inside the oxygenator during cardiopulmonary bypass and never open these lines if the arterial pressure is insufficient. Additionally, blood sampling from the extracorporeal circuit immediately after initiating or during weaning from cardiopulmonary bypass should be performed only by personnel fully trained in the procedure.

6. Myocardial Protection

In MICS, aortic cross-clamping is performed through a narrow intercostal view. Therefore, special attention must be paid to ensuring adequate aortic occlusion. One solution is to monitor aortic root pressure (root pressure) during infusion of cardioplegia solution [16]. After aortic cross-clamping, confirm that the root pressure differs from arterial pressures, such as the radial artery pressure. If they are identical, incomplete clamping is suspected and should be reported to the surgeon. In mitral valve surgery, caution is also required regarding aortic regurgitation caused by the left atrial retractor used to secure the surgical field [16]. If aortic occlusion is incomplete, there is a risk that arterial flow may enter the coronary arteries, diluting the cardioplegia solution. Therefore, after aortic cross-clamping, confirm via arterial pressure monitor that the pulsation of the heartbeat is not being transmitted to systemic blood pressure. Additionally, during cardioplegia solution infusion for aortic valve regurgitation, confirm cardiac arrest or pulsation again with ECG monitoring.

Recent reports have demonstrated the usefulness of myocardial protection methods using del Nido with a single dose or prolonged intermittent periods of approximately 60 minutes [16-24]. It should be noted that many of these reports are studies conducted with relatively short cross-clamp times of approximately 90-120 minutes. Typically, MICS procedures tend to have longer cardiopulmonary bypass times and cross-clamp times compared to median sternotomy [25]. Furthermore, the learning curve required to master the technique also tends to prolong aortic cross-clamp time [26, 27]. Indeed, incidents attributed to prolonged cardioplegia dosing

intervals during MICS have been reported on [28].

Due to limited surgical field visibility, the line for administering cardioplegia may sometimes be extended. In MICS, where the field of view is restricted, the cardioplegia line may not be sufficiently primed, connections in the extended section may be loose causing leaks, or air bubbles may be mixed without the surgeon noticing. During cardioplegia administration, pay close attention to mixing air bubbles. Furthermore, when using an extension tube connected to the circuit used during thoracotomy access, check for air bubbles within the line and be mindful of residual air bubbles at the connection points. Additionally, since direct manual air removal from the heart is not possible before aortic cross-clamp release, attention must also be paid to residual air within the heart.

When modifying the myocardial protection protocol during the initiation of a new MICS procedure, the surgical team should discuss the administration method, composition of the cardioplegia solution, administration intervals, and their upper limits of administration intervals, referencing textbooks, past literature, and forthcoming cardioplegia guidelines.

7. Suction and Venting

In MICS, suction and vent lines are limited, and particularly in robotic surgery, the number of suction lines tends to be reduced. Typically, suction using a roller pump with a 1/4-inch inner diameter tube provides a maximum flow rate of approximately only 1.5 L/min even at full speed, making it impossible to cover the entire circulation with a single suction line. Furthermore, depending on the suction cannula or tube, negative pressure within the suction line may become excessive. If conversion to open surgery is required due to bleeding, situations may arise where suction alone is insufficient. Therefore, the surgical team should preoperatively consider the use of suction and vent to maintain systemic circulation and ensure a clear surgical field.

It is recommended that the surgical team observe the color of suctioned blood. If arterial blood is present, consider the impact of bleeding and take appropriate actions such as temporarily increasing the flow rate or prioritizing hemostasis by performing circulatory arrest. These actions should be performed with information shared among the team.

8. MICS-Specific Complications

The surgical team must share awareness of complications specific to MICS. Reports indicate that conversion to median sternotomy was necessary due to right lung injury from adhesions following right mini-thoracotomy, complications associated with peripheral cannulation, aortic dissection, massive hemorrhage, and poor visualization caused by inadequate venous drainage [29]. Therefore, preparations must anticipate conversion to median sternotomy and

the potential need for emergency selective cerebral perfusion. Additionally, it has been reported that the risk of re-expansion pulmonary edema increases in cases with prolonged cardiopulmonary bypass time, chronic respiratory disease, pulmonary hypertension, and right ventricular dysfunction [30,31]. At the institutions collaborating on this statement, body temperature is controlled around 32° C to prevent re-expansion pulmonary edema.

9. Target Perfusion Flow

In recent years, Goal-Directed Perfusion (GDP) has been advocated [32]. However, due to the aforementioned constraints, the target perfusion flow rate may be reduced compared to open-chest surgery. It is recommended to maintain the target oxygen delivery while considering hypothermia if perfusion flow rate decreases. When hypothermia is used to maintain circulation, it is recommended to evaluate the oxygen demand-supply balance during rewarming.

10. Management of $PaCO_2$

To prevent air embolism, carbon dioxide is used in the surgical field during cardiac and laparoscopic surgery[33]. In MICS, carbon dioxide insufflation is also performed to prevent air embolism. However, this creates a hypercapnic environment within the thoracic cavity, and aspirating this carbon dioxide through surgical suction often results in hypercapnia. Therefore, it is crucial to monitor arterial blood carbon dioxide partial pressure over time or perform blood gas analysis more frequently than usual, and to avoid unnecessarily increasing the rotation speed of the suction pumps.

11. Layout of the Heart-Lung Machine

For cardiopulmonary bypass in MICS, the placement of endoscopic equipment and robotic systems necessitates reconsideration of the heart-lung machine's positioning. Typically, endoscopic monitors and robotic patient carts are placed at the patient's head side, directly facing the surgeon. Therefore, the surgical team must conduct simulations beforehand to confirm the operating room's dimensions, equipment placement, locations of power outlets and medical gas terminals, and the length of the CPB circuit and cardioplegia circuit, as well as the surgeon's movement routes.

At the institution contributing to this statement, during open procedures, the heart-lung machine is placed on the patient's left temporal side. However, for MICS, a large monitor is placed at the head, necessitating placement of the heart-lung machine at the caudal side. Furthermore, since the surgical field can be shared with the surgeon via monitors, it is recommended to place a surgical field monitor in a position visible to the perfusionist.

12. Acquisition of Cardiopulmonary Bypass Skills for MICS

When performing cardiopulmonary bypass for MICS for the first time, it is recommended to observe procedures at institutions with prior experience and consult with the methods of extracorporeal circulation beforehand. Also, in the initial case, consider the presence of a perfusionist who is accustomed to MICS CPB. Until MICS becomes a standard procedure at your institution, it is recommended not to perform MICS CPB for the first case performed for perfusionist training purposes. Furthermore, because surgical techniques are performed within a restricted surgical view, it may be difficult to grasp the entire surgical field. Therefore, good communication with the surgical field is necessary to prevent circuit problems and other issues before they occur.

13. Conclusion

The demand for MICS is expected to continue increasing. However, we must fully understand its risks, master appropriate extracorporeal circulation techniques, and implement reliable safety measures.

Interprofessional collaboration and a team-based approach are crucial in MICS. As perfusionists, we must strive to improve our extracorporeal circulation skills alongside advances in surgical techniques. It is often challenging to communicate issues arising from extracorporeal circulation to cardiac surgeons, who are focused on the small surgical field and perform complex procedures with advanced techniques. We must strive for regular information sharing within the surgical team. Perfusionists should proactively communicate any intraoperative concerns or issues to the surgical team. Furthermore, we expect perfusionists to contribute to patient safety through practices like the “two-challenge rule“.

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