21 Anesthetic Challenges in Minimally Invasive Cardiac Surgery

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Evolution of Minimally Invasive Cardiac Surgery

Interest in minimal-access surgery continues to grow in all surgical fields, including cardiac surgery, with a range of procedures using less invasive methods. A median sternotomy had been the conventional approach for all types of cardiac procedures, but minimally invasive cardiac surgery has proven to be a reliable alternative with short-term and long-term benefits [1–3]. According to the Society of Thoracic Surgeons, minimally invasive cardiac surgery (MICS) is "any procedure not performed with a full sternotomy and cardiopulmonary support" [4, 5].

MICS procedures discussed in this chapter include procedures that are performed via incisions smaller than a full sternotomy (Fig. 21.1) and, in some cases, without cardiopulmonary bypass (CPB), such as operations performed for coronary artery bypass and classic heart valve surgery.

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General Concepts for MICS

1. *Preoperative Challenges and Considerations*

   A thorough patient assessment is required before all cardiac surgery procedures. Additionally, the following assessments are required for those who may be candidates for MICS:

   (a) **Computed tomography (CT) of the thoracic cavity and abdomen with three-dimensional reconstruction**. CT will reveal chest anatomy and chest-wall abnormalities such as scoliosis, pectus carinatum, or pectus excavatum; adhesions from prior lung irradiation or thoracic cavity surgery; and the presence and extent of ascending aortic calcification. CT imaging of the iliofemoral vessels can identify the tortuosity and extent of calcification that may influence the site of arterial cannulation and cannula size, which are details needed for establishing CPB.

   (b) **Pulmonary function tests.** These assessments can identify patients with severe pulmonary disease who might not tolerate single-lung ventilation during surgery.

   (c) **Contraindications for transesophageal echocardiography (TEE).** Esophageal pathology that may contraindicate placement of TEE should be identified since the TEE exam is invaluable in many cardiac surgery cases.

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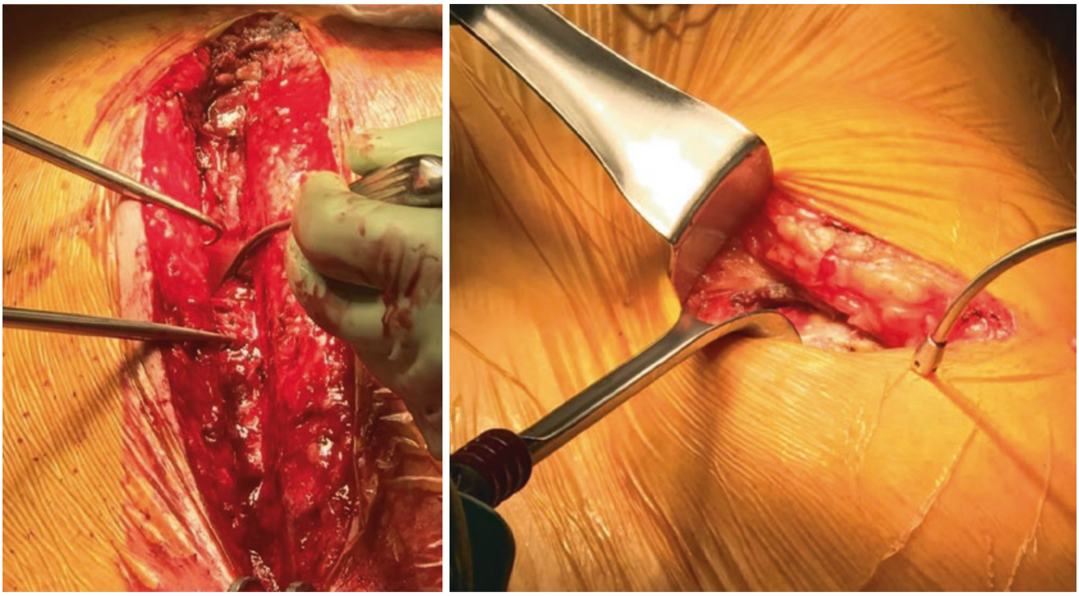

Fig. 21.1 Illustrations from an anesthesiologist's view of Left: traditional midline sternotomy and Right: an anterior mini-thoracotomy

2. *Monitoring*

MICS is conducted with standard American Society of Anesthesiologists (ASA) monitors, which include the five-lead electrocardiogram, capnograph, pulse oximetry, and core temperature, plus other monitoring:

(a) Urine output checked during MICS for volume (to assess adequacy of renal perfusion) and color (to evaluate for hemolysis)
(b) Neuromuscular blockade. Monitoring is vital since appropriate muscle relaxation is essential to avoid sudden patient movement during the procedure while stabilizers are in use or the robot is docked.
(c) Invasive monitoring: intra-arterial (pre-induction) and central venous access
(d) Pulmonary artery catheters with pacing capability. This capability is important in MICS for aortic valve replacement, when the surgeon has limited access to the right ventricle for temporary placement of epicardial wires.
(e) Neurologic monitoring: This includes, near-infrared spectroscopy based cerebral oximetry to monitor cerebral saturation, to provide early detection of a mal-positioned inflated endo-aortic occlusion balloon catheter (EAOBC), and processed electroencephalogram (e.g. bispectral index) for monitoring the depth of anesthesia.
(f) TEE: TEE is especially valuable in MICS because of the inherently limited access to the thorax and mediastinum which obstructs the surgeon's direct view of the heart [6].
   (i) A pre-bypass TEE will help confirm the preoperative diagnosis.
   (ii) If peripheral CPB is planned, TEE can guide the cannulation of the inferior vena cava, where the guidewire is visualized passing through the femoral vein to the inferior vena cava (IVC) to the right atrium and superior vena cava (SVC). A femoral venous bicaval cannula is inserted over the guidewire, and the distal end is positioned a few centimeters above the SVC- right atrium (RA) junction (Fig. 21.2).

TEE can also help guide the cannulation of the femoral artery: After surgical

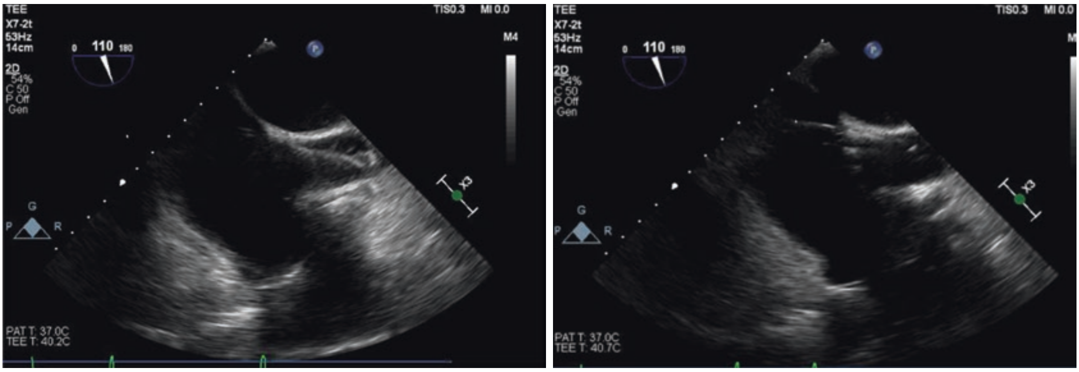

Fig. 21.2 TEE images. Left: midesophageal bicaval view with guide wire in the right atrium and SVC. Right: midesophageal bicaval view with femoral venous bicaval cannula positioned above the SVC-RA junction

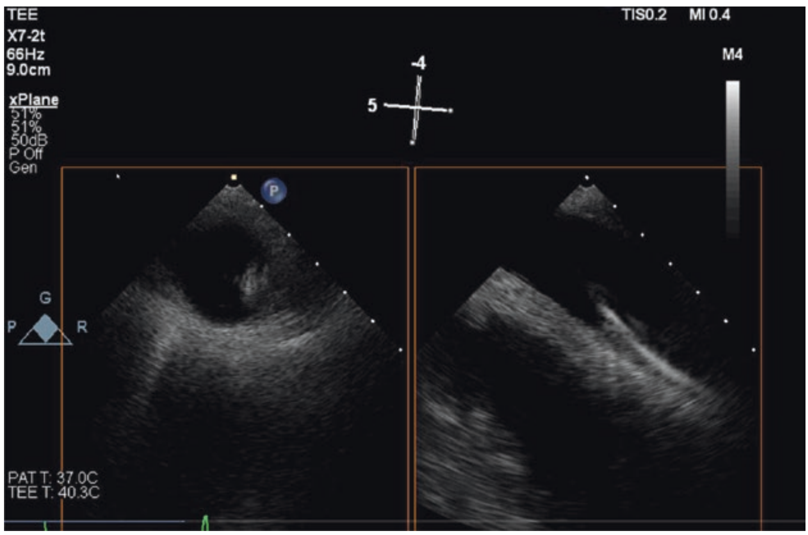

Fig. 21.3 TEE images: X plane of the midesophageal descending aorta in the short and long axis views documenting that the guidewire is in the lumen and not in the wall

exposure of the artery, a guidewire is introduced and passed into the descending aorta. Visual confirmation that the curled J-tip guidewire is in the lumen and not in the wall is needed prior to insertion of the femoral cannula to avoid aortic dissection.

This positioning of the guidewire is seen in short and long axis views of the midesophageal descending aorta (Fig. 21.3).

(g) When required, TEE also guides the placement of a coronary sinus catheter for retrograde delivery of cardioplegia. This is can be seen in the modified midesophageal bicaval view, where the tricuspid valve comes into view at 110–130°.

(h) TEE is used to guide the placement of the EAOBC (if utilized), and to continuously monitor the location of the inflated balloon during CPB and to detect possible migration of the balloon.

(i) TEE is essential for assessing the adequacy of venting and de-airing.

(j) TEE can detect new-onset abnormalities of the left ventricular regional wall motion, which is the basis of diagnosing myocardial ischemia.

(k) TEE also assesses volume status and function of the left and right ventricles, especially during CO2 insufflation.

(l) TEE assesses cardiac and valvular function and confirms a successful surgical procedure at the end of the operation.

(m) TEE is used to guide placement of an intra-aortic balloon pump if it is needed for weaning from CPB.

3. *Preparation for Surgery and Positioning of the Patient*

Most MICS procedures require that the patient be in the supine position, with modifications to maximize exposure of the surgical site. Further information regarding patient positioning will be described later in the chapter.

4. *Various Approaches and Incisions*

Approaches for minimally invasive coronary artery bypass graft surgery are illustrated in Fig. 21.4.

(a) Anterior lateral mini thoracotomy in the left fifth intercostal space. Length of the incision depends on the procedure type.

(b) Anterior lateral mini thoracotomy with smaller incisions for heart positioner and stabilizer

(c) Multiple smaller incisions for a robotic approach

Approaches for mini-aortic valve replacement (AVR): a 5–10-cm incision is usually required [7].

The two most common approaches are:

(a) Partial upper sternotomy with J-shaped extension into the right third or fourth interspace [8]

(b) Right anterior mini-thoracotomy incision in the second or third intercostal space

Less common approaches:

(a) Inverted T-shaped mini-sternotomy

(b) Right parasternal incision

(c) Trans-sternal incision

The most widely used incisions are illustrated in Fig. 21.5.

Approaches for mini-mitral valve replacement (MVR):

(a) Partial lower mini sternotomy

(b) Right parasternal incision

(c) Right mini-thoracotomy through the 3rd or 4th interspace

(d) Multiple smaller incisions for a robotic approach

The most widely used incisions are illustrated in Fig. 21.6.

5. *Anesthesia conduct*

Anesthesia for these procedures follows the same principles as for conventional cardiac anesthesia, but with differences. Distinct considerations are the need to maintain hemodynamic stability and allow for fast emergence from anesthesia with early tracheal extubation. Thus, a tailored balanced anesthesia technique with short-acting medications, rather than the commonly used high-dose opioid regimen, is recommended.

6. *Lung Isolation*

Single-lung ventilation during MICS in cases that involve entry into the thoracic cavity is essential for the surgeons' visualization of cardiac structures. A left-sided double-lumen endotracheal tube (DLT) or a bronchial blocker inserted through a single-lumen endotracheal tube can be used. Left-sided DLT may be the preferred option in cardiac opera-

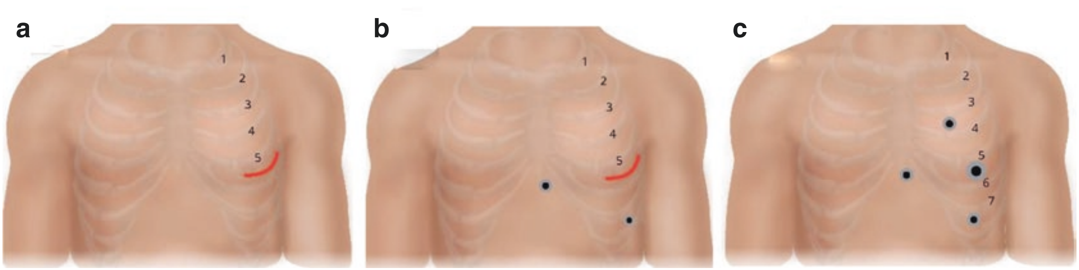

Fig. 21.4 Approaches for minimally invasive coronary artery bypass graft surgery. (**a**) Left anterior mini-thoracotomy. (**b**) Left anterior mini-thoracotomy with stabilizer ports. (**c**) Multiple smaller incisions for robotic ports

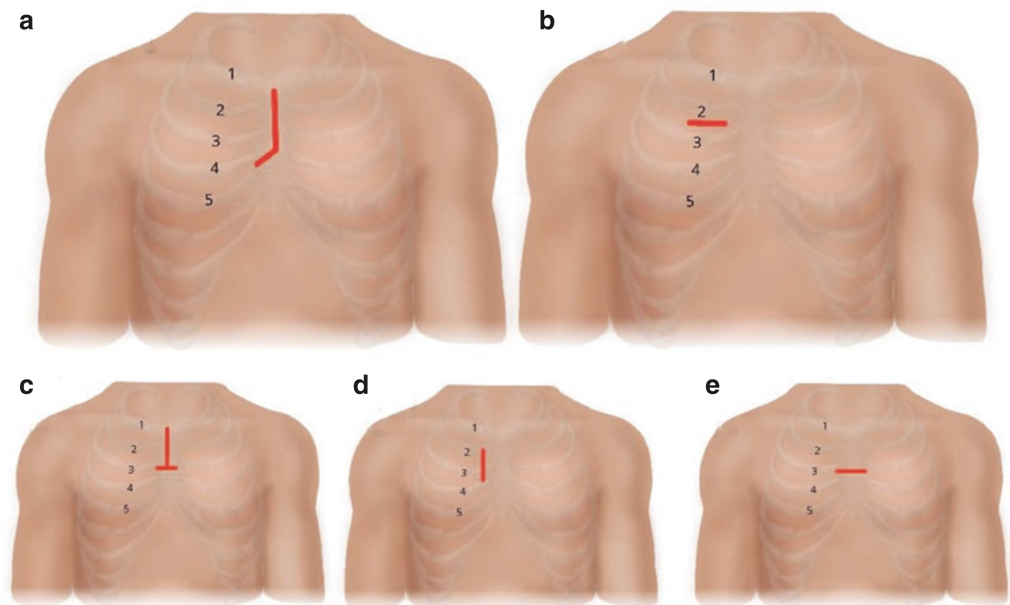

Fig. 21.5 Approaches for minimally invasive aortic valve surgery. The most widely used incisions are (**a**) Upper (J) mini-sternotomy. (**b**) Right anterior mini-thoracotomy. The less common incisions are (**c**) Inverted 'T' incision. (**d**) Right parasternal incision. (**e**) Transverse sternotomy

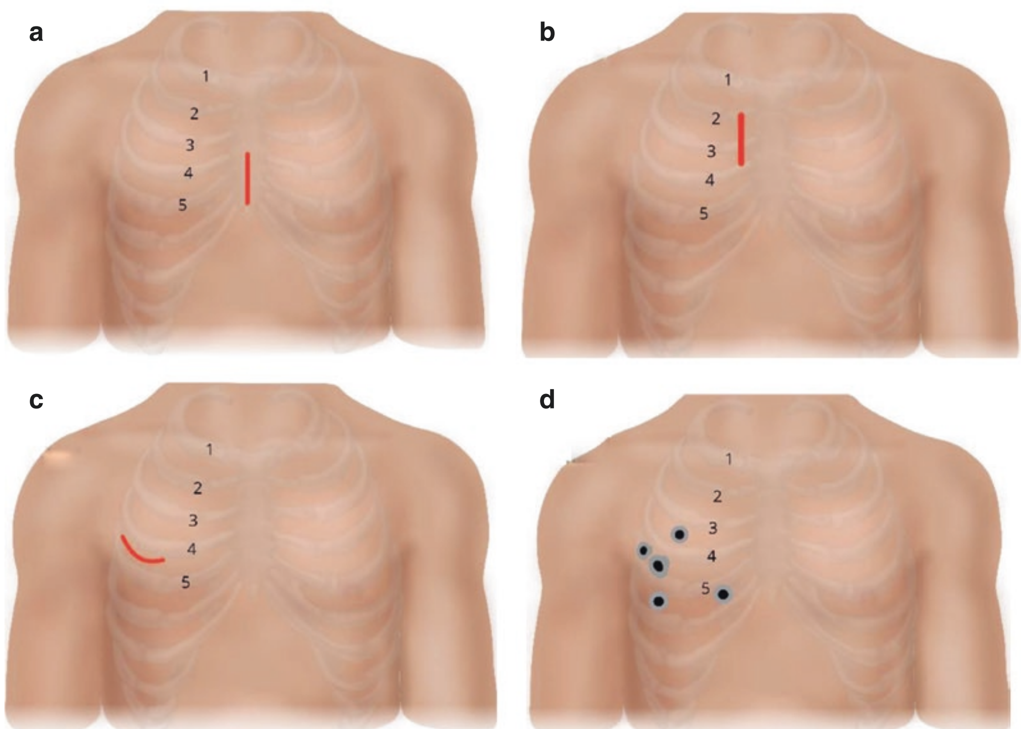

Fig. 21.6 Approaches for minimally invasive mitral valve surgery. The most widely used incisions are (**a**) Lower hemisternotomy. (**b**) Right parasternal incision (**c**) Right lateral mini thoracotomy. (**d**) Multiple smaller incisions for a robotic approach

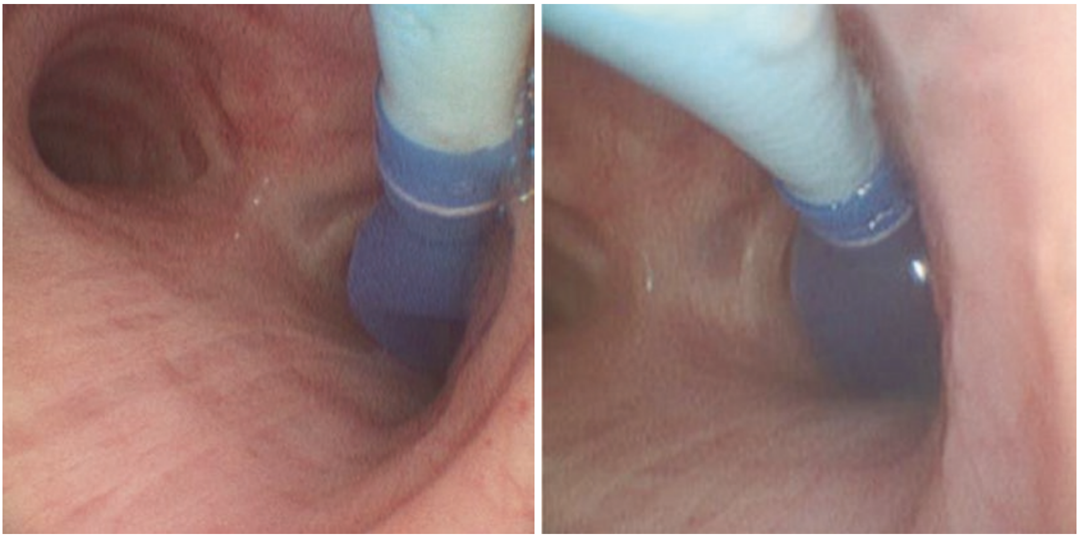

Fig. 21.7 Endobronchial blocker for single-lung ventilation with the balloon in the right main bronchus: Left: balloon not inflated. Right: balloon inflated

tions performed with a left mini-thoracotomy, since these operations tend to be of shorter duration and have less airway edema at the end, and positioning of the bronchial blocker may be more difficult as the left main bronchus is more acutely angulated. On the other hand, for cardiac operations with a right mini-thoracotomy, where right lung deflation is needed, a bronchial blocker may be the choice of preference, as it is easier to position and has a lower incidence of sore throat and vocal cord injuries (Fig. 21.7).

In addition, these right mini-thoracotomy MICS operations tend to be longer and associated with more airway edema, so avoiding tube exchange at the end of the procedure is desirable.

Four types of endobronchial blockers are commercially available: Rusch® EZ-Blocker™, Arndt® wire-guided blocker, Cohen Flexi-tip BB (Cook Critical Care), and Fuji Uni-blocker (Fuji Systems, Tokyo).

7. *Pain Management*

   To aid in the early recovery from MICS, the use of opioids should be minimized. As such, regional anesthesia techniques can be used to decrease the need for intraoperative and postoperative opioid consumption:

   (a) Single-shot, multilevel intercostal nerve block with long-acting bupivacaine (EXPAREL) injected by the surgeon.
   (b) Paravertebral (T2–T3) block is an effective option to aid in early emergence and extubation.
   (c) Erector Spinae Plane (ESP) block or continuous catheter can provide excellent analgesia for unilateral chest wall incisions.
   (d) Ultrasound-guided serratus anterior plane block (SAPB) can help anesthetize lateral cutaneous branches of intercostal nerves that provide sensation to chest wall incisions.

8. Early Extubation and Fast-Track Management

   The invasive nature of cardiac surgery is associated with significant morbidity, especially surgical access-site complications. MICS was developed to minimize these complications and permit early extubation and post-operative fast-track recovery. The potential benefits to a fast-track approach in MICS includes:

(a) fewer ventilator-associated complications (accidental extubation, mucus plugging of the endotracheal tube, pulmonary barotrauma, and ventilator-associated pneumonia)

(b) reduced requirements for sedation in the ICU
(c) early patient mobilization
(d) early ICU discharge
(e) reduced hospital length of stay
(f) lower cost

The Spectrum of Minimally Invasive Techniques

Minimally Invasive Coronary Revascularization Coronary Artery Bypass Graft (CABG)

Various surgical approaches for minimally invasive CABG, which have similar short and long-term postoperative mortality and morbidity, are used. These revascularization strategies include approaches via small thoracotomy incisions (to "preserve sternal integrity") with or without the use of CPB (Fig. 21.8).

Examples of some of the methods are:

- **Off-pump CABG with median sternotomy** [9, 10]. In this approach, CPB and cardioplegic arrest are avoided. Thus, blood elements do not contact the foreign surfaces of the CPB circuit, which could trigger the systemic inflammatory response. Also, deliberate hypothermia while on CPB, and the subsequent risk of post-operative coagulopathy are avoided. Lastly, this approach avoids cannulation of the aorta, which might result in aortic injury (Fig. 21.9).

Anesthetic Challenges of OPCAB

- Off-pump CABG (OPCAB) is a minimally invasive alternative to conventional CABG with CPB, especially for high-risk patients with multiple comorbidities.
- Maintaining myocardial oxygen supply-demand equilibrium to prevent myocar-

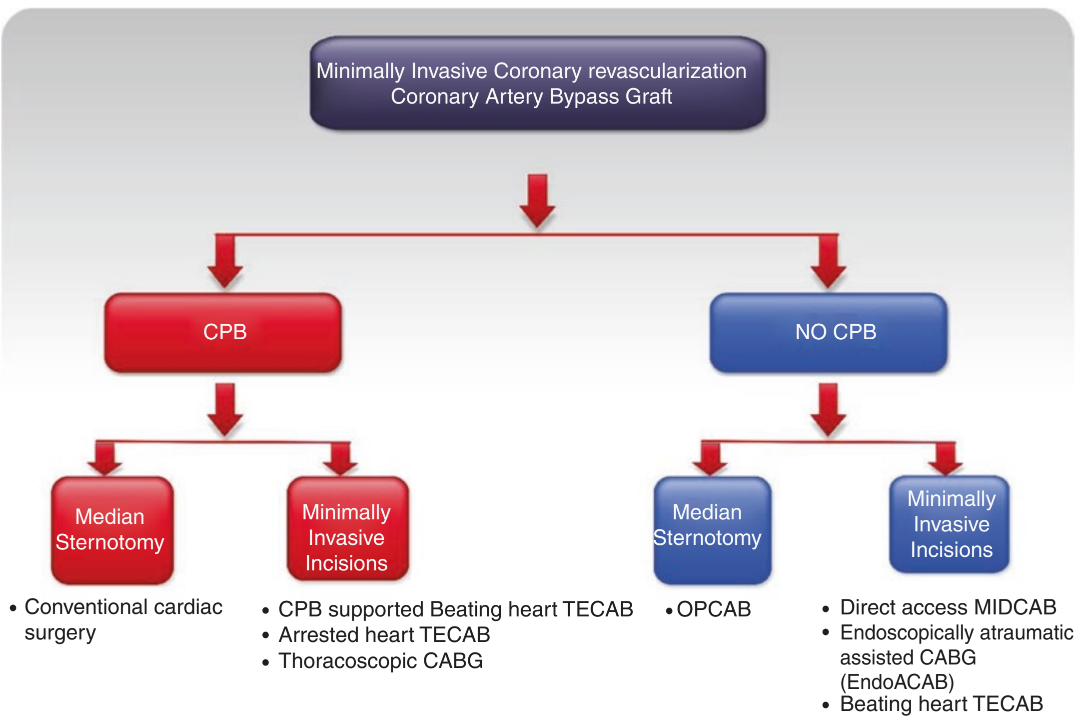

Fig. 21.8 Minimally invasive approaches for coronary revascularization (coronary artery bypass graft [CABG])

dial ischemia during induction of anesthesia and the period prior to revascularization is a priority during these cases.

- The major anesthetic challenge is the maintenance of hemodynamic stability during cardiac manipulation and from ischemia during distal anastomosis. Hemodynamic stability may be achieved with fluid volume administration and, if needed, vasopressor support.
- Diligent ECG monitoring of arrhythmias that may develop as a result of insufflation of air into the distal anastomosis is of paramount importance. Rapid intervention will prevent emergency conversion to an on-pump CPB. Bradycardia often occurs during right coronary artery grafting, which is treatable with ventricular pacing.
- Monitoring for myocardial ischemia during graft anastomosis is essential. Typically, some degree of new onset ST-segment changes (depression or elevation) occurs. Thus, TEE examination for regional wall motion abnormalities is vital; treatment with nitroglycerin may be indicated.
- Ischemia, heart positioning, or both, may lead to worsening mitral regurgitation [11, 12], which may further contribute to hemodynamic instability. Mitral regurgitation is usually easily seen on TEE and is treated by decreasing the stabilizer pressure or adjusting the heart position.
- Maintaining normothermia is a challenge due to the extensive exposure of the body to atmospheric temperature required and the limited body-surface area available for active warming. Preventive or corrective measures include continuous warming of intravenous fluids, raising the operating room temperature, and using an underbody heating blanket.

- **Minimally invasive direct coronary artery bypass (MIDCAB)** [13] is performed through a small left anterolateral mini-thoracotomy without CPB and cardioplegic arrest. The left internal mammary artery is harvested under direct vision (Fig. 21.10). With a stabilizer on the beating heart, this artery is anastomosed to the left anterior descending coronary or diagonal artery. MIDCAB was introduced in the 1990s, but it fell out of favor because of concerns over post-thoracotomy pain from rib-spreading and chest-wall retraction. With newer, improved rib spreaders and chest retractors, interest in MIDCAB is rising again.
- **Thoracoscopic MIDCAB, also referred to as endoscopically atraumatic assisted CABG (EndoACAB)**

  In this approach, thoracoscopy is combined with a mini-thoracotomy to minimize chest-wall retraction and rib-spreading [14]. The procedure was developed as an alternative to robotic- assisted CABG to avoid the high cost of robotics. The left internal mammary artery is harvested using thoracoscopy via a small-access port, and the vessel is anastomosed to the left anterior descending artery of the beating heart through a mini-thoracotomy.
- **Minimally Invasive Multivessel Coronary Artery Bypass Grafting (MICS CABG), also known as Multivessel Small Thoracotomies (MVST)**

  This operation is a multivessel operation that accomplishes complete revascularization, mainly, all-arterial, for the treatment of multivessel disease. The incision for the mini thoracotomy is made more laterally than for MIDCAB, in the left fifth intercostal space, to allow rib spreading without rib injury. This incision allows harvesting of the entire length of the left internal mammary artery and the right internal mammary artery under direct visualization and making multiple proximal aortic anastomoses possible using an anastomotic device, e.g. Heartstring. It also utilizestwo port-site incisions: one access-port incision in the left 7th intercostal space for

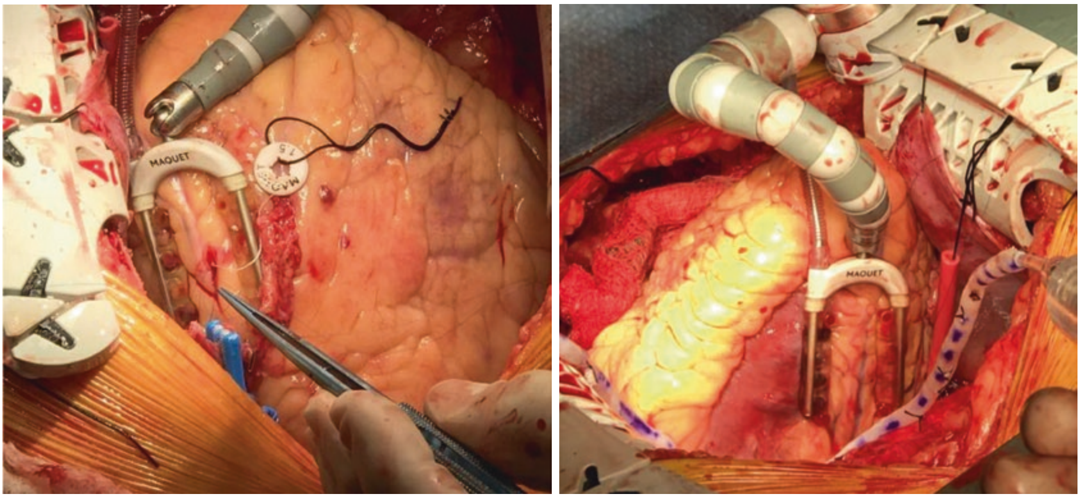

Fig. 21.9 Images of anesthesiologist's view showing distal coronary anastomoses using Octopus stabilization device for off-pump coronary artery bypass

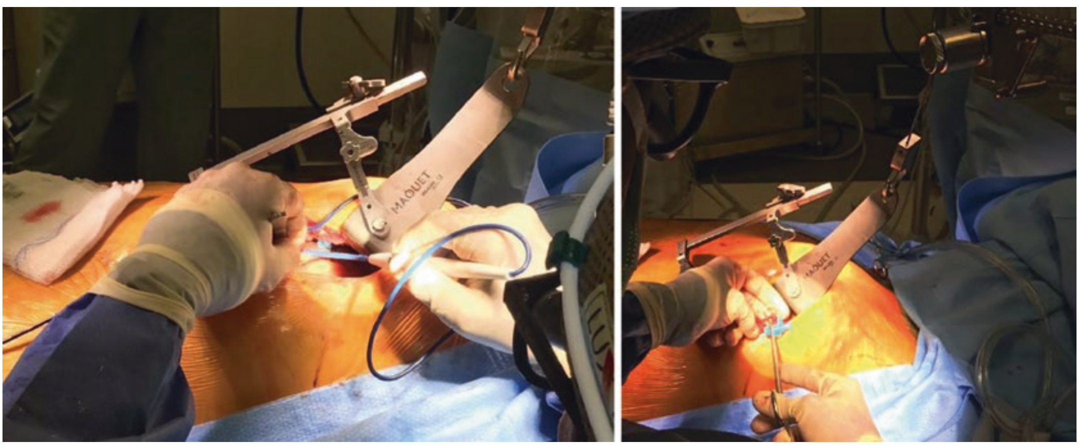

Fig. 21.10 Images of Surgeon's view showing small left anterolateral mini-thoracotomy and the left internal mammary artery is harvested under direct vision

the epicardial stabilizer and another access-port incision for the apical positioner in the subxiphoid (Fig. 21.11). MICS CABG is usually performed on a beating heart [15, 16]. Other variations of multivessel minimally invasive techniques for CABG have been described. An earlier technique to MICS CABG, called the anterolateral thoracotomy/coronary artery bypass (ALT-CAB), used a generous anterolateral thoracotomy incision without the two port-site incisions [17]. Another technique is the bilateral MIDCAB-based approach, which involves bilateral anterior mini-thoracotomies.

- **Totally endoscopic CABG (TECAB) and robotic-assisted CABG.**

Robotic-assisted CABG is the most technically advanced of these procedures because of the high-quality imaging and magnification afforded by the robot camera, coupled with improved range of motion by the robotic instruments. However, it has significant costs and the longest learning curve. The Da Vinci system (Intuitive Surgical, Mountain View,

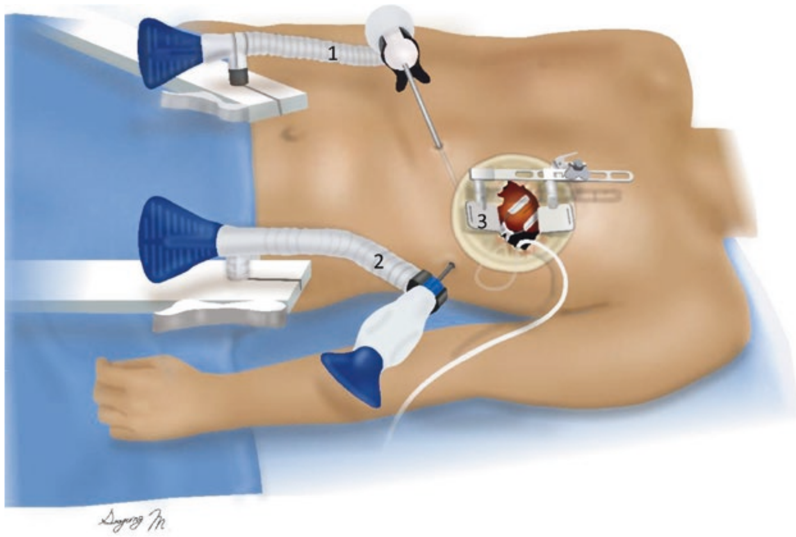

Fig. 21.11 Minimally invasive multivessel CABG with application of minimally invasive stabilizers. (1) Starfish non-sternotomy heart positioner; (2) Octopus Nuvo tissue stabilizer; (3) minimally invasive retractor system

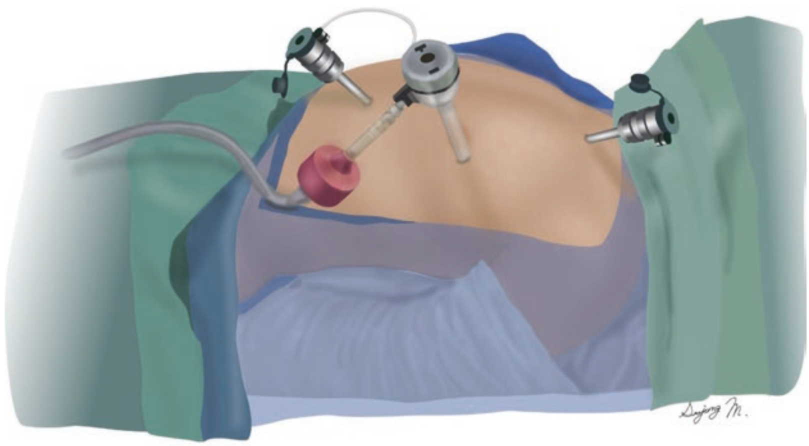

Fig. 21.12 Totally endoscopic CABG with arm positioning and port placement during TECAB

CA) is commercially available and consists of a surgeon console that remotely manipulates micro instruments in a precise fashion. A camera port and two instrument ports are inserted into the patient's left chest to accommodate the robotic arms (Fig. 21.12).

A fourth arm is added to the newer generation da Vinci Surgical System, which can be used to insert endostabilizers, thus facilitating off-pump or on-pump anastomoses. The surgical instruments are attached to the docked robotic arms. Robotic-assisted CABG [18] is performed in various ways, including robotic-assisted MIDCAB, in which the left internal mammary artery is harvested with a robot via a port, and the vessel is anastomosed to the target coronaries through a mini-thoracotomy. Total endoscopic CABG (TECAB) is achieved when the entire coronary revascularization is performed endoscopically, using robotically-enhanced telemanipulation [19, 20]. TECAB can be performed as an arrested heart TECAB, beating heart TECAB with CPB, or beating heart TECAB without CPB.

– *TECAB on the arrested heart (AH-TECAB).*
– Arresting the heart for TECAB provides a bloodless, motionless flaccid heart to facilitate endoscopic suturing of the anastomosis. The innovative endovascular catheter system allows femoral arterial retrograde perfusion with peripheral CPB established in the groin via the common femoral artery and

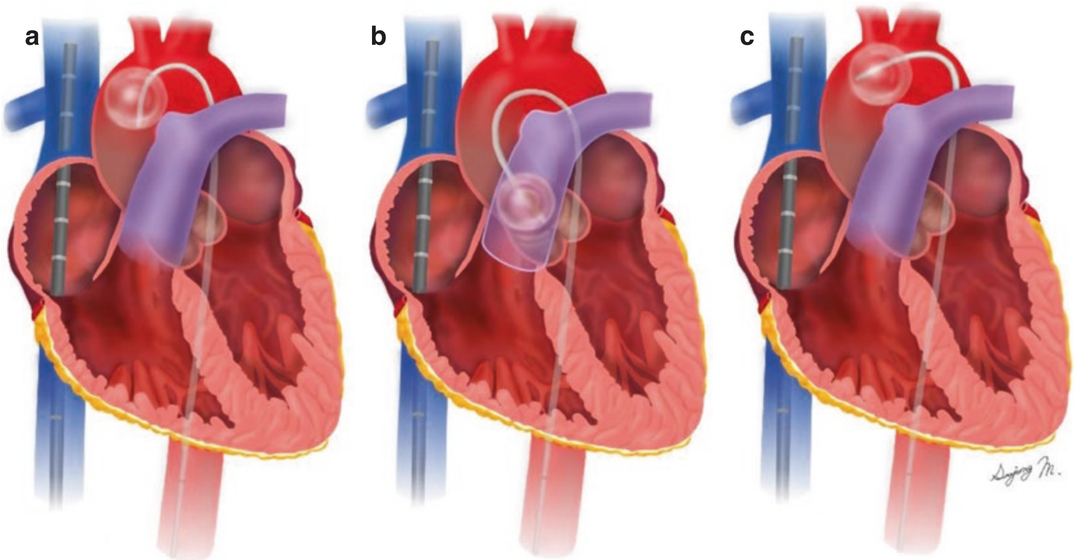

Fig. 21.13 Endoaortic occlusion balloon catheter positioning leading to aortic cross-clamp. (**a**), correct balloon position. (**b**), proximal migration. (**c**), distal migration

vein cannulation. A balloon-tipped catheter, called the endoaortic occlusion balloon clamp, is inserted into the femoral artery and advanced into the ascending aorta distal to the coronaries and proximal to the origin of the arch vessels [21]. The balloon clamp provides aortic occlusion, antegrade perfusion through the distal channel into the aortic root, and venting of the left heart through the same channel (Fig. 21.13).

– TECAB on the beating heart with CPB support (pump-assisted BH-TECAB).
– The advantages of using CPB assist in BH-TECAB is the optimal surgical exposure created by deflation of both lungs. The deflation reduces technical difficulties by unloading the heart, and CPB provides safety in case of the development of ventricular fibrillation when the robot arms are docked, as resuscitation and emergent femoral cannulation are extremely difficult in this situation.
– TECAB on the beating heart without CPB (BH-TECAB).

  Beating heart TECAB should be considered when the transfemoral approach for CPB cannulation is not feasible due to aortoiliac atherosclerosis or small vessel caliber, both of which make insertion of the EAOBC hazardous. The benefits of avoiding CPB are as mentioned earlier. The development of several new technologies have enabled implementation of CBP-free approaches: the addition of a fourth arm to the DaVinci S ™ robotic system; the new endoscopic coronary stabilizer (the Intuitive Endo-wrist™ stabilizer); and the automated distal anastomotic devices that establish anastomosis without disrupting blood flow through the target coronary vessel.

Surgical Technique for Sternal-Sparing Minimally Invasive Coronary Revascularization

The standard anesthesia workflow for sternal sparing minimally invasive coronary revascularization is as follows:

1. Moving the patient to the operating room table; placement of R2 defibrillation pads in a location that avoids the surgical site; place-

ment of all ASA monitors; and placement of an arterial line, if not already placed in the surgical holding area.

2. Induction of anesthesia; securing the airway with DLT or bronchial blocker; and confirmation of proper position of the DLT or bronchial blocker via fiberoptic bronchoscopy.
3. Next, a TEE probe is inserted into the esophagus. A double-lumen central venous catheter is inserted into the right internal jugular vein. If percutaneous CPB and an arrested heart is planned, a second arterial line is inserted into the contralateral radial artery. Also, an EndoVent pulmonary catheter (Edwards Lifesciences, Irvine, CA) and percutaneous retrograde coronary sinus catheter are needed. These catheters are usually inserted and positioned under visualization with TEE and fluoroscopic guidance.
4. The patient is positioned according to the type of approach, usually at 30° right lateral decubitus, with a small roll below the scapula and the left arm either posteriorly placed at the patient's side or elevated over the head with an arm support. The right arm is either tucked or extended for radial artery harvesting.
5. The surgical skin is prepped and draped as for open CABG, in case conversion to an open operation is needed.
6. Then surgery is initiated and single-lung ventilation with CO_2 insufflation is started.

   Depending on the approach, the following steps may be taken:

   (a) A mini thoracotomy incision is made with a retractor placed, and the left internal mammary and, possibly, the right internal mammary artery are harvested. After the grafts are optimized for anastomosis, heparin is administered. The necessary anastomoses are made.

   (b) TECAB. After the camera port is placed, single-lung ventilation and CO2 insufflation (to allow for adequate intra-thoracic space), are initiated. Instrument ports are inserted under camera vision. The robot is docked, and grafts are harvested. Heparin is injected, and the robotic endostabilizers are positioned for distal anastomosis.

   (c) If peripheral CPB is planned, heparin is administered after the grafts are harvested. TEE guides arterial and venous cannulation. CPB is started, and the EAOBC is inflated, serving as an aortic cross clamp. The heart is arrested by infusion of cardioplegia to the aortic root via the distal channel in the EAOBC. The necessary anastomoses are made, and CPB is weaned.
7. The incisions are closed, and in cases utilizing a DLT, the airway is changed to a single-lumen endotracheal tube. In uncomplicated cases where appropriate levels of anesthesia, narcotic and neuromuscular blockers have been utilized, early extubation in the OR may be considered.
8. The patient is brought to the intensive care unit.

Anesthetic Challenges for MIDCAB, EndoACAB, MICS CABG, and TECAB

- Due to the complexity of these operations, communication with the cardiac surgeon is crucial, especially for: timing for one-lung ventilation; level of CO2 insufflation pressure; heparin administration; detecting and correcting malposition of the endoballoon in femoro-femoral CPB; detecting and correcting regional wall-motion abnormalities in the beating-heart approach.
- The major anesthetic challenge is the development of hemodynamic instability after initiation of single-lung ventilation, which is intensified when intrathoracic insufflation of carbon dioxide is used. The instability can result in hypoxia, progressive hypercarbia, pulmonary hypertension, hypoxic pulmonary vasoconstriction, decreased venous return, and increased right ventricular strain, with significant reduction in cardiac index. Positive end expiratory pressure on the ventilated lung, to bring the aorta into surgical view, can further

decrease venous return. Interventions to minimize hemodynamic compromise are prompt administration of intravenous fluid boluses, infusion of vasopressors, and limiting carbon dioxide insufflation pressure to <10 mmHg.

- R2 defibrillation pads are placed on the patient during the pre-induction period. Sterile defibrillator pads are available and may be used after prepping to avoid surgical sites.
- The most common reason for failure of lung isolation with a DLT is failure to recognize the true carina. The true carina can be confirmed with visualization of the trifurcation of the right upper lobe bronchus from the right main bronchus, "the only place that has three orifices." Corrective measures for this problem are withdrawal of the DLT after the tracheal cuff is deflated, guiding the endobronchial lumen of the DLT over the fiberoptic bronchoscope into the left main bronchus, then switching the bronchoscope into the tracheal lumen and observing for inflation of the bronchial cuff at the rim of left main bronchus. The most common reason for failure of lung isolation with a bronchial blocker is dislodgement (herniation) of the balloon; repositioning with the help of the bronchoscope, usually solves the problem. An uncommon reason for failure with a bronchial blocker is origination of the right upper lobe directly from the supracarinal trachea. In this circumstance, using two separate bronchial blockers has isolated the lung successfully [22, 23]
- Unilateral re-expansion pulmonary edema that sometimes develops in single-lung ventilation procedures can be prevented by administering neutrophil elastase inhibitor by intravenous infusion at 0.2–0.25 mg/kg/h from the beginning of anesthesia until the patient is extubated in the postoperative period [24] and by starting two-lung ventilation prior to weaning off CPB.
- Diligent monitoring for ventricular arrhythmias is imperative. Management of ventricular fibrillation in these procedures is challenging: internal defibrillation is not feasible and external defibrillation is less effective, as R2 defibrillation pads are often not placed in an optimal position and insufflated CO_2 attenuates the defibrillation electric current. In addition, chest compressions in BH-TECAB are difficult to perform until the robot is undocked. Lidocaine or amiodarone infusions have been described to lessen the risks of developing VF.
- Bilateral radial arterial lines are required to monitor arterial blood pressure proximal and distal to the EAOBC balloon in on-pump cases where an EAOBC clamp is used. Bilateral arterial lines will help in recognizing dislodgement of the inflated balloon resulting in occlusion of the innominate artery.
- Another challenge for the anesthesia provider in TECAB cases is loss of access to the patient airway after turning the bed to facilitate robot docking.
- Peripheral CPB increases the risk of aortic dissection and cerebral embolization, so confirmation that the guidewire is intraluminal with TEE is critical.
- Accurate placement of the percutaneous retrograde coronary sinus cardioplegia catheter is achieved by using TEE and fluoroscopic guidance.
- For on-pump cases, a bolus of intravenous adenosine will facilitate a rapid cardiac arrest.
- Another challenge for the anesthesiologist in these procedures is changing the DLT to a single lumen endotracheal tube at the end of surgery, when the tongue and upper airway are edematous

and the patient is coagulopathic. The use of video laryngoscopy and two airway exchanger catheters, one in each limb, provides a safe way to change tubes under direct vision.

- Monitoring for myocardial ischemia in these cases is not optimal, given that some of the ECG leads are placed more posteriorly to avoid the operative site of the chest.

Minimally Invasive Mitral Valve Surgery (MIMVS)

1. *Mitral Valve Anatomy* [25]

   The mitral valve apparatus is a complex structure comprising the following:
   (a) Mitral annulus
   (b) Anterior and posterior mitral valve leaflets
   (c) Chordae tendineae
   (d) Papillary muscles
   (e) Wall of the left ventricle
2. *Patient selection and contraindications* [26]

   Patients for MIMVS must be selected judiciously. Suitability is evaluated on an individual basis. Contraindications for MIMVS include:
   (a) Significant aortic root dilation
   (b) Poor lung function or severe pulmonary hypertension that prevent tolerability of single-lung ventilation
   (c) Aortoiliac atherosclerotic disease or a tortuous descending aorta that prevents peripheral arterial cannulation
   (d) Severe aortic valve regurgitation causing difficulties in arresting the heart with antegrade cardioplegia
   (e) Prior pneumonectomy
   (f) Severe circumferential mitral annular calcification
3. *The surgical procedure main events* [27–30] *for MIMVS are these:*
   (a) *Intraoperative Monitoring and Lines:* Moving the patient to the operating room table; placement of R2 defibrillation pads avoid the surgical site; placement of all ASA monitors; and placement of an arterial line, if not already placed in the surgical holding area.
   (b) *Anesthesia Conduct:* Induction of anesthesia; securing the airway with DLT or bronchial blocker; and confirmation of proper position of the DLT or bronchial blocker via fiberoptic bronchoscopy.
   (c) *TEE:* A TEE probe is inserted into the esophagus, and a double-lumen central venous line is inserted into the right internal jugular vein.
   (d) *Positioning:* The patient is positioned supine close to the edge of the right side of the operating table. The right side of the chest is elevated 30°, with a small roll placed inferior to the scapula, and the right arm is slightly flexed and positioned safely behind the posterior axillary line and supported by the table at the side. The left arm is tucked, with pressure points padded. The operating table usually is tilted to the left (Fig. 21.14).
   (e) *Skin prepping and draping:* This should be done in the usual manner, with large

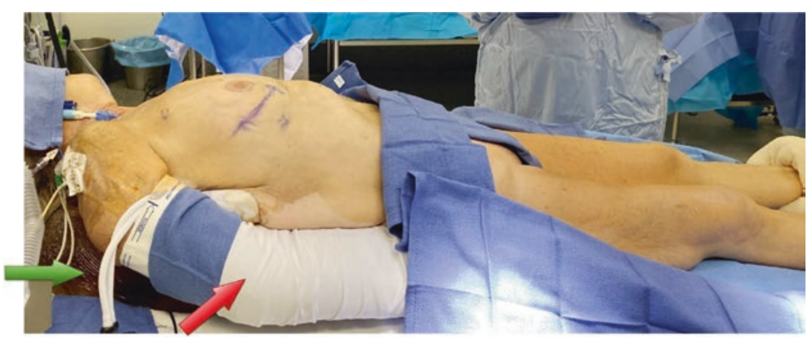

Fig. 21.14 Patient positioned and marked for MIMVS prior to surgery. Notice: a small roll placed inferior to the scapula (green arrow), and the right arm is slightly flexed (red arrow)

exposure to the operating site covering the right side of the chest, sternum, and both groins.

(f) *Incision and exposure:* Types of incisions have been mentioned earlier in the general concepts section. Depending on visualization, there are three different categories:

(i) Direct vision through the mini incision. The current trend is to use a right mini-thoracotomy in the inframammary fold and through the 4th or 5th intercostal space lateral to the anterior axillary line, thus preserving sternal integrity. An example of this exposure and mitral valve repair is shown in Fig. 21.15.

(ii) Direct vision with 2D endoscopic video-assistance. This includes the right mini-thoracotomy and three small incisions: one for insertion of the thoracoscope via the second intercostal space; one entry site for the left atrial retractor; and one for insertion of a Chitwood transthoracic aortic cross-clamp (Scanlan International, Minneapolis, MN) in the third intercostal space. An external flexible aortic cross-clamp can be used instead of the transthoracic clamp (Fig. 21.16).

(iii) 3D Robot-assisted MIMVS through multiple smaller port incisions. A camera port is placed in the 4th inter-

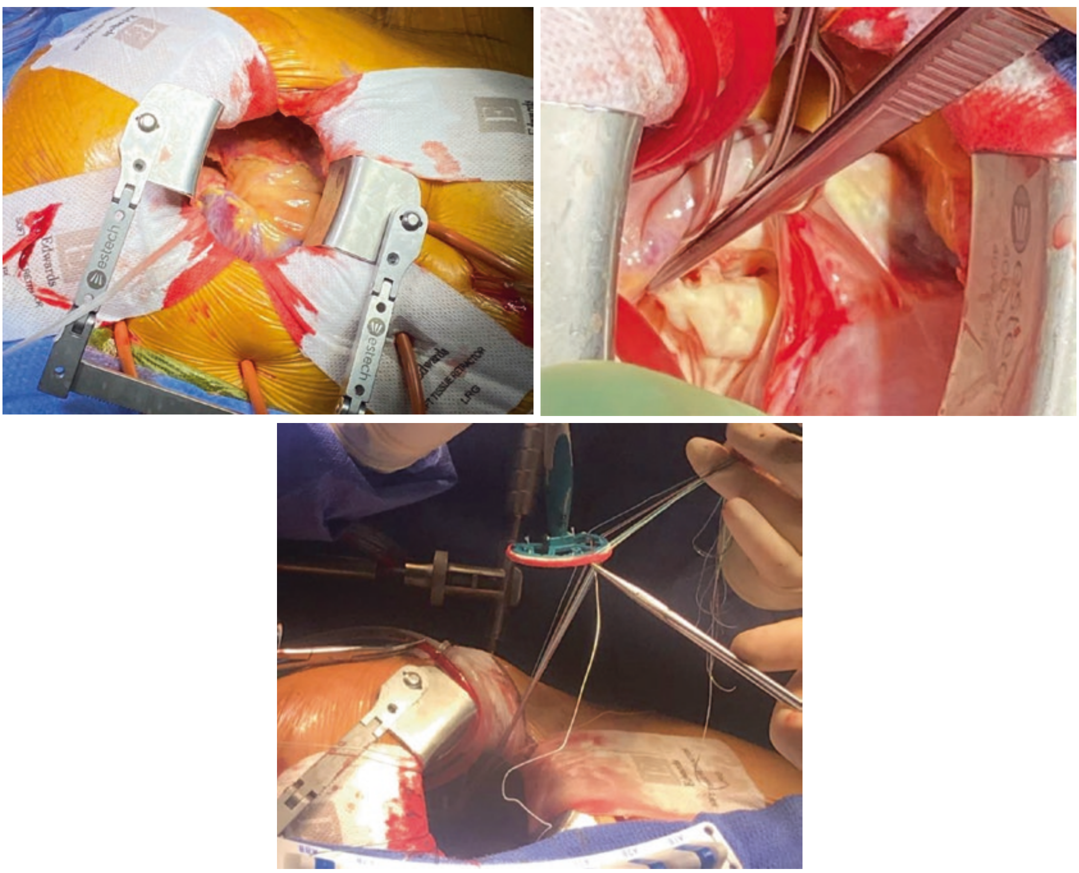

Fig. 21.15 Surgeon's view. Top Left: right mini-thoracotomy incision with soft-tissue retractor and metal retractor system in place, exposing the right atrium. Top Right: mitral valve exposed, showing two rupture chordae of the posterior leaflet (forceps). Bottom: suturing annuloplasty mitral ring

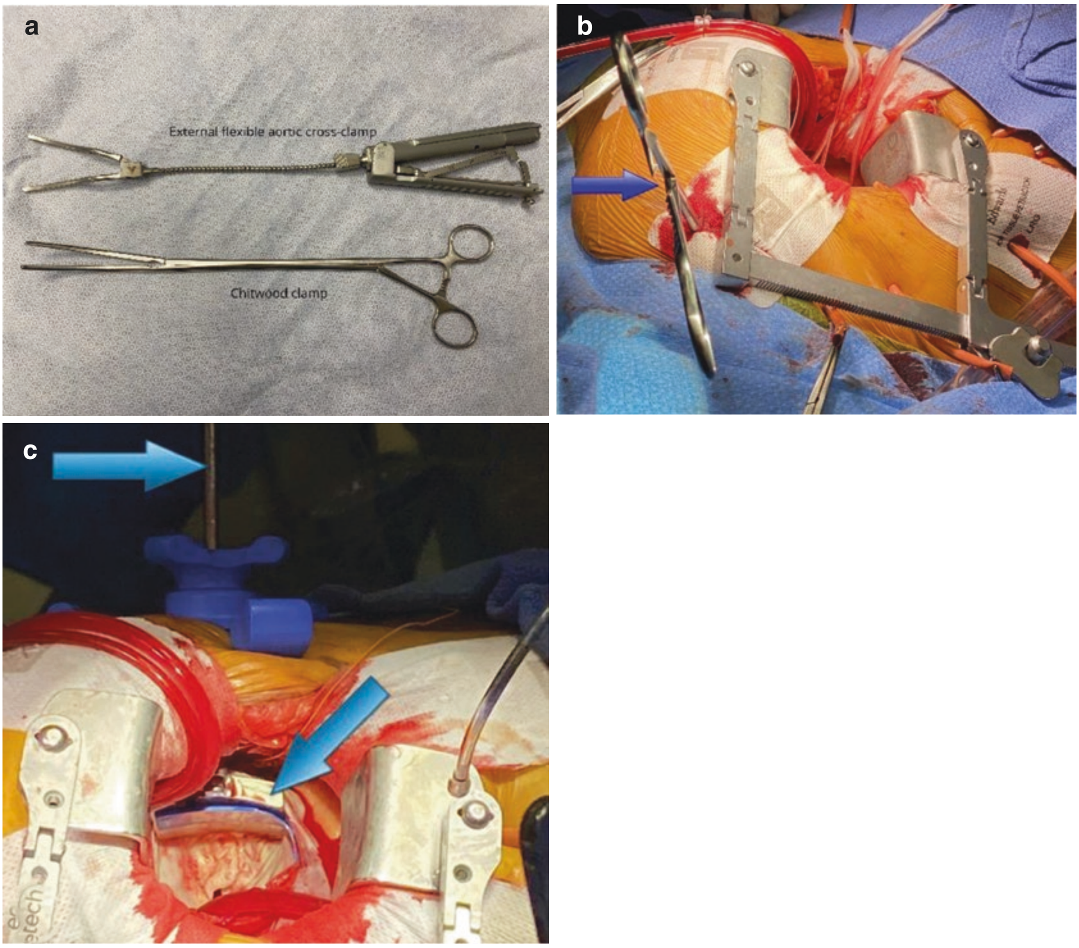

Fig. 21.16 (**a**) Top: External flexible aortic cross-clamp. Bottom: Chitwood transthoracic aortic cross-clamp (**b**) Surgeon's view Chitwood transthoracic aortic cross-clamp in place (blue arrow) with a different stab, (**c**) left atria retractor (blue arrows) through a separate stab incision for placement

costal space at the anterior axillary line; a left atrial retractor arm is placed in the 5th intercostal space medial to the midclavicular line; the left robotic arm is in the 3rd intercostal space at the midaxillary line; the working port in the 4th intercostal space lateral to the camera port; and the right robotic arm in the 5th intercostal space lateral to the anterior axillary line. If use of an aortic endo-balloon is contraindicated, a Chitwood transthoracic aortic cross-clamp is inserted via an entry-site incision in the third intercostal space (Fig. 21.17).

(g) *Cardiopulmonary Perfusion:* Several cannulation approaches are available, ranging from standard aorto-bicaval cannulation directly through the surgical incision to complete peripheral femoro-femoral cannulation [31, 32]. Central aortic cannulation may be accomplished after the surgical field is exposed. Following systemic heparinization, the distal ascending aorta is cannulated with a flexible non-kinking aortic cannula. A bicaval venous cannula and antegrade cardioplegia catheter are also inserted through the mini thoracotomy incision (Fig. 21.18). Peripheral cardiopulmonary perfusion is established to avoid placing

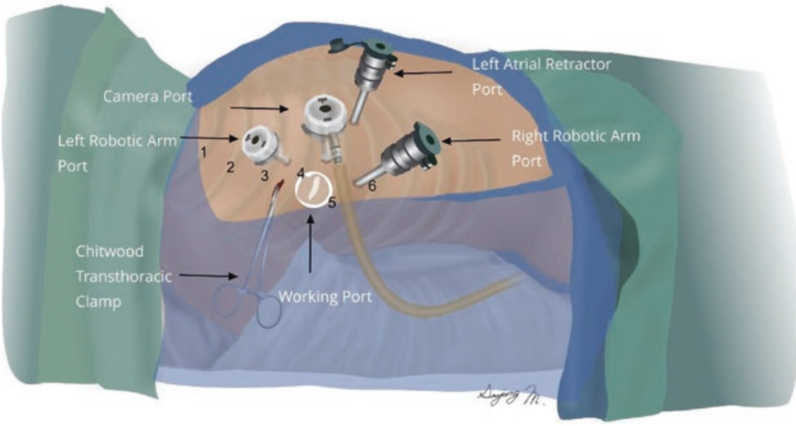

Fig. 21.17 Robotic mitral valve port placement

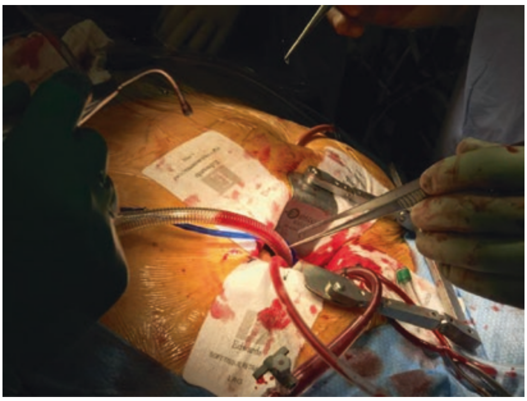

Fig. 21.18 Anesthesiologist's view of a centrally cannulating CPB circuit through mini thoracotomy incision

cannulas through a small incision, which could compromise working space and limit visibility. Perfusion is accomplished via retrograde femoral arterial perfusion through a small incision in the groin. Venous drainage is accomplished with a long multiport femoral venous cannula with vacuum assistance of −40 mmHg, which enables adequate venous drainage through a small cannula. Modern wire-reinforced cannulae tend to have excellent flow properties, since their inner diameter is larger relative to their outer diameter. The femoral venous cannula is inserted through the same groin incision and positioned into the SVC. An open peripheral femoro-femoral cannulation is the most-often used technique for CPB in MIMVS (Fig. 21.19).

(h) *Aortic Cross-Clamping:* Multiple options are available for aortic cross-clamping, including an endoaortic occlusion balloon catheter (Edwards Lifesciences, Irvine, CA) or by direct aortic clamping. The aorta can be directly clamped with a Chitwood transthoracic aortic cross-clamp, applied through a separate small third intercostal space incision, or with an external flexible aortic cross-clamp applied through a mini-thoracotomy incision (Fig. 21.16).

(i) *Myocardial Protection and cardioplegia administration:* Several techniques for myocardial protection have been described [33]. Antegrade cardioplegia can be achieved in the usual fashion with a combined Y-shape cardioplegia/aortic vent long catheter placed into the ascending aorta through the mini incision, or through a separate stab wound into the second or third intercostal space. Single-shot antegrade cardioplegia can be administered via a long needle directly in the aortic root. Antegrade cardioplegia can be also delivered through the EAOBC. In the case of aortic regurgitation, retrograde cardioplegia can be delivered through a percutaneous coronary sinus catheter via the internal jugular vein placed by the anesthesiologist or directly into the right atrium by the surgeon.

(j) *Mitral Valve Exposure:* The mitral valve is exposed by a left atriotomy through a transseptal incision and then applying a

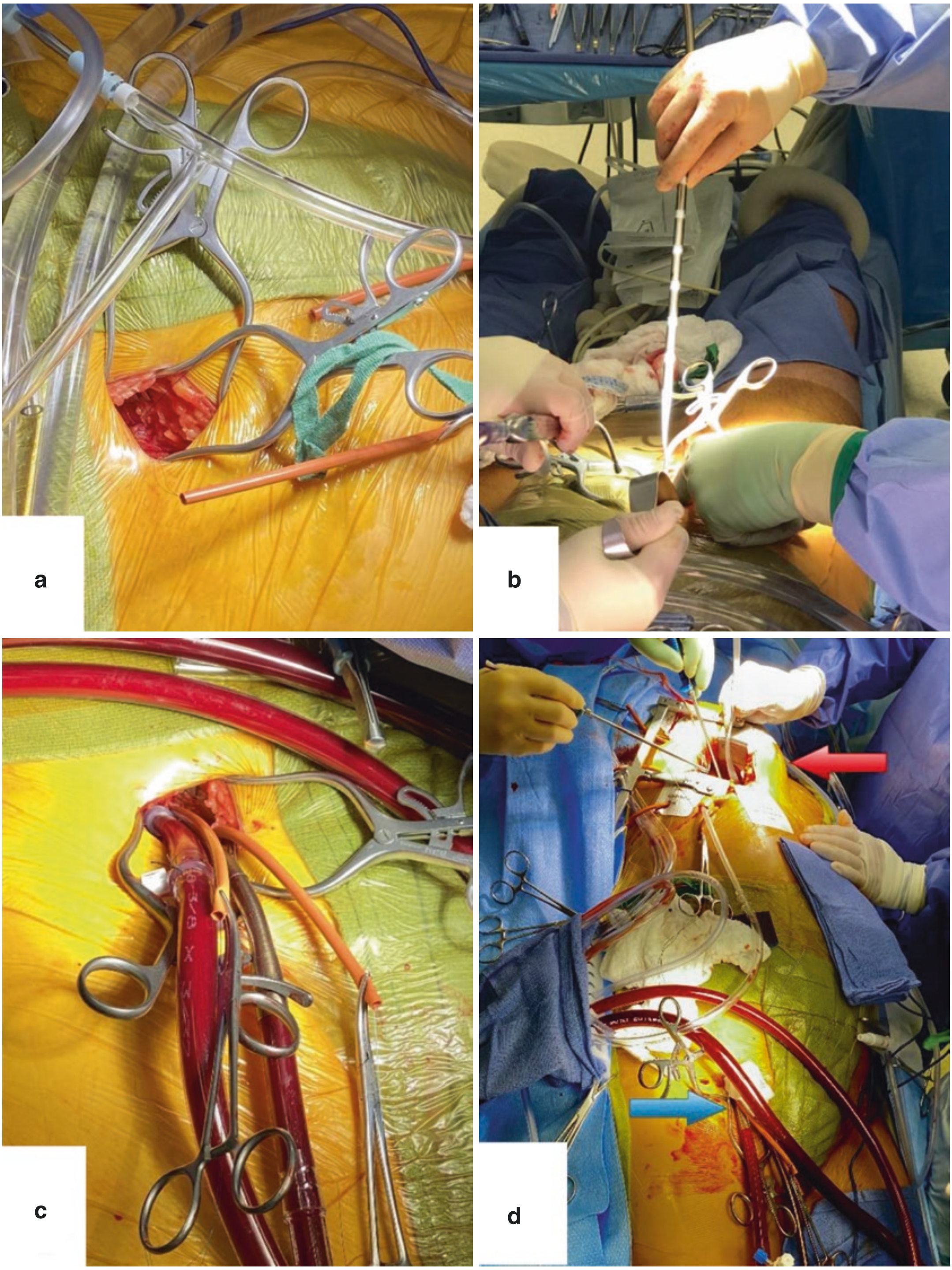

Fig. 21.19 Steps for achieving peripheral CPB circuit. (**a**) A small groin incision exposes the femoral artery and vein. (**b**) Femoral venous cannula is advanced over a guidewire in the right groin. (**c**) The right femoral artery and vein are cannulated. (**d**) Femoro-femoral bypass (blue arrow) and mini thoracotomy incision for MIMVS (red arrow)

self-retaining left atrial retractor to pull in the anterior wall of left atrium and the septum. The retractor is manually adjusted to ensure an unobstructed view of the mitral valve. Thereafter, traditional mitral valve replacement or repair techniques are used.

(k) *De-airing, Decannulation, and Closure:* After the mitral valve procedure is completed, the atrial wall and septum are closed. A temporary epicardial pacing wire is then placed on the right ventricle, followed by placing the patient in the Trendelenburg position and removing the aortic cross-clamp. De-airing of the heart is achieved by applying suction in the aortic root vent, insufflating CO_2 throughout the operation, initiating antegrade cardioplegia, and filling the left ventricle. TEE guides the de-airing process. Next, the patient is weaned from CPB. TEE is performed to check adequacy of the mitral valve procedure, absence of iatrogenic aortic regurgitation, and for assessment of ventricular function. Decannulation and protamine administration are conducted in a standard fashion.

Minimally Invasive Aortic Valve Replacement (MIAVR) [34–37]

1. *Aortic Valve Anatomy*

   The aortic valve apparatus is a complex structure composed of:
   (a) Aortic annulus at ventriculoaortic junction
   (b) The aortic root, which is made up of
      (i) three semilunar cusps, the left coronary, right coronary and non-coronary cusps
      (ii) the sinuses of Valsalva
      (iii) left and right coronary ostia
   (c) Sinotubular junction
2. *Patient selection and contraindications*

   Aortic valve surgery is performed most often to treat severe aortic valve stenosis (Fig. 21.20) or regurgitation. Patient selection for minimally invasive aortic valve surgery is key for a successful operation. Besides the considerations discussed in the preoperative assessment section, these contraindications are specific for MIAVR:
   (a) Small aortic annulus requiring reconstruction
   (b) Significant aortic root dilation

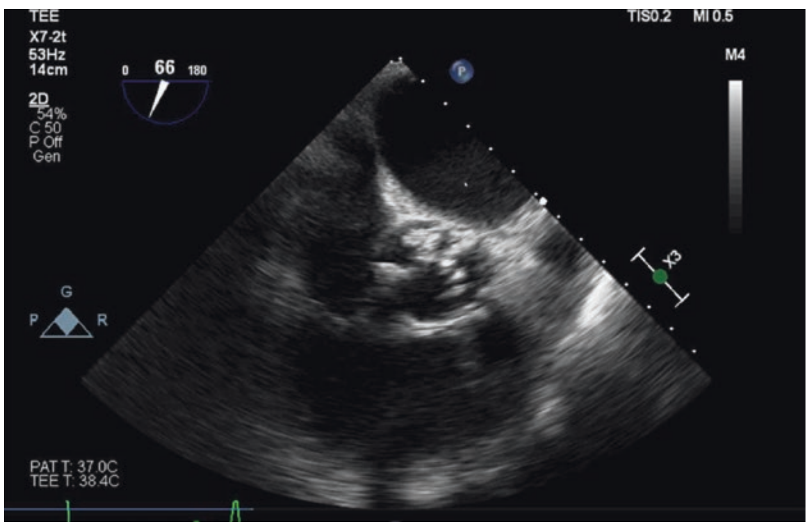

Fig. 21.20 TEE image in the midesophageal aortic valve short-axis view revealing severe stenotic aortic valve

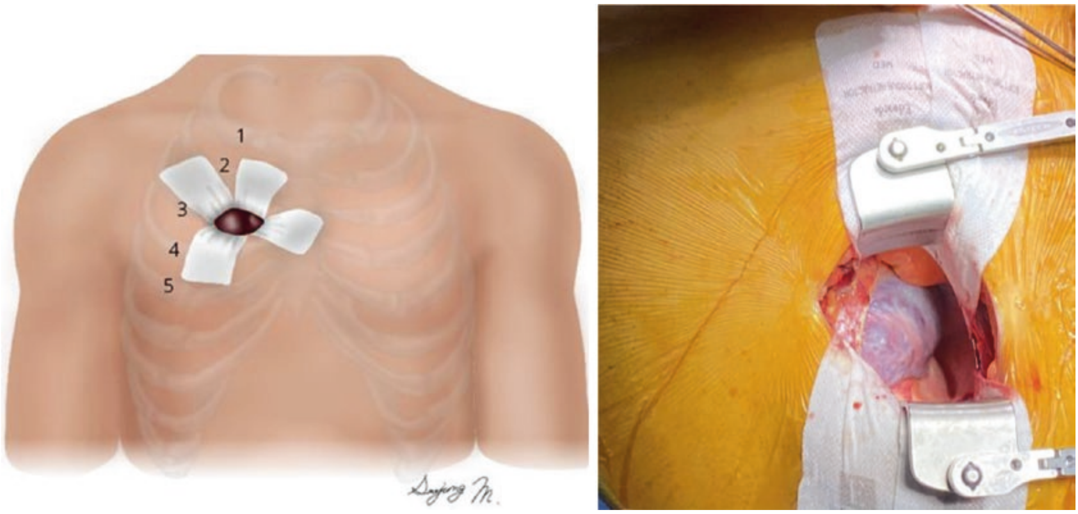

Fig. 21.21 Left: Right anterior mini-thoracotomy incision. Right: Anesthesiologist's view of right anterior mini-thoracotomy incision for mini AVR

   (c) Aortoiliac atherosclerotic disease that prevents peripheral arterial cannulation
   (d) Severe ascending calcification ("porcelain aorta") or presence of mobile atheroma
   (e) Poor left ventricular function
   (f) Significant coronary artery disease
3. *The main procedural events for MIAVR are as follows:*
   (a) *Intraoperative monitoring, lines, anesthesia conduct, and TEE:* The actions are the same as for MIMVS.
   (b) *Positioning:* The patient is positioned supine close to the edge of the right side of the operating table with both arms tucked.
   (c) *Skin prepping and draping:* This should be carried out in the same manner as for MIMVS.
   (d) *Incision and Exposure:* Types of incisions have been mentioned earlier in the general concepts section. The two most common operative approaches used are the upper (J) mini-sternotomy approach and the right anterior mini-thoracotomy approach (Fig. 21.5a, b). The limited upper mini-sternotomy incision is followed by a right anterior mini-thoracotomy at the level of the third or fourth intercostal space. The right anterior mini-thoracotomy approach is performed through a 4–6-cm transverse skin incision at the level of the second or third intercostal space (Fig. 21.21). After the intercostal space is entered, single-lung ventilation is initiated, and a soft tissue retractor is placed to allow visualization of the intrathoracic structures. Then, an intercoastal metal retractor is placed to improve exposure. Afterwards, the pericardium is opened to expose the aorta.
   (e) *Cardiopulmonary Perfusion:* Depending on the type of incision, CPB is accomplished either centrally or peripherally. Central CPB is initiated by aorto-right atrial cannulation under direct vision through the incision. Arterial outflow can be achieved by central cannulation of the distal ascending aorta, and venous drainage is achieved by cannulation of the right atrium. Peripheral CPB can be achieved through arterial cannulation of the axillary or femoral artery. For venous cannu-

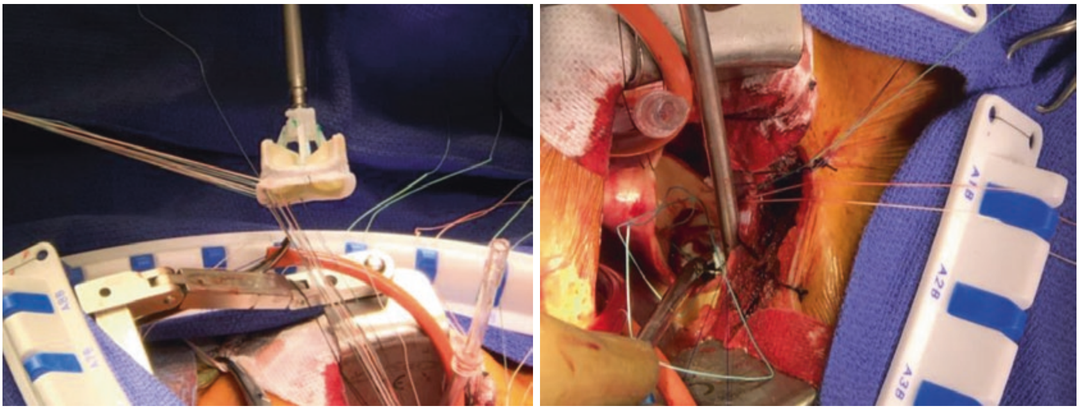

Fig. 21.22 Anesthesiologist's view of mini AVR through right thoracotomy. Left: sewing anchoring sutures of the bioprosthetic aortic valve. Right: inserting the bioprosthetic aortic valve in the aortic root

lation, bicaval-cannulation accessed through the femoral vein is usually adequate with or without vacuum-assisted drainage.

(f) *Aortic cross-clamping, myocardial protection and cardioplegia administration:* Myocardial protection and aortic cross-clamping are identical to those for MIMVS.

(g) *Aortic Valve Exposure:* After the aorta is cross-clamped and the heart is arrested, the aorta is opened, and the valve is exposed. The aortic leaflets are resected and the annulus is debrided, leaving the annulus free of calcification. The prosthetic aortic valve is then sutured with interrupted sutures in the sewing ring, then implanted with a long knotting device (Fig. 21.22).

(h) *Sutureless aortic valve replacement:* The two types of sutureless aortic prostheses that are currently available are the Intuity (Edwards Lifesciences) sutureless valve and the Perceval sutureless valve (Sorin, Saluggia, Italy). These valves can be rapidly deployed. For the Intuity valve, the annulus is sized, and three annular stitches from the nadir of each sinus are stitched to the valve sewing ring. The valve is then deployed with balloon expansion.

(i) *De-airing, Decannulation, and Closure:* After the aortotomy is closed, de-airing is done under TEE guidance with CO_2 continuously insufflated in the field and the aortic cross-clamp removed. With the patient still on CPB and before filling the heart, atrial and ventricular epicardial pacing wires are placed. The patient is then weaned from CPB. The aortic valve is evaluated with TEE before decannulation and protamine administration. Once drains are placed, local anesthetics [e.g. bupivacaine and/or liposomal bupivacaine (EXPAREL) can be administrated via intercostal nerve block and infiltration along the entire surgical field. Finally, the incisions are closed (Fig. 21.23).

Anesthetic Challenges for Minimally Invasive Valve Surgery

- The anesthetic challenges for minimally invasive valve surgery are similar to those for other minimally-invasive heart operations discussed earlier (page 22).
- The unique anesthetic challenge for minimally invasive valve surgery is the ability to de-air the heart, since it is difficult for the surgeon to access the left ventricle.
- De-airing is achieved by a variety of techniques discussed in the text.

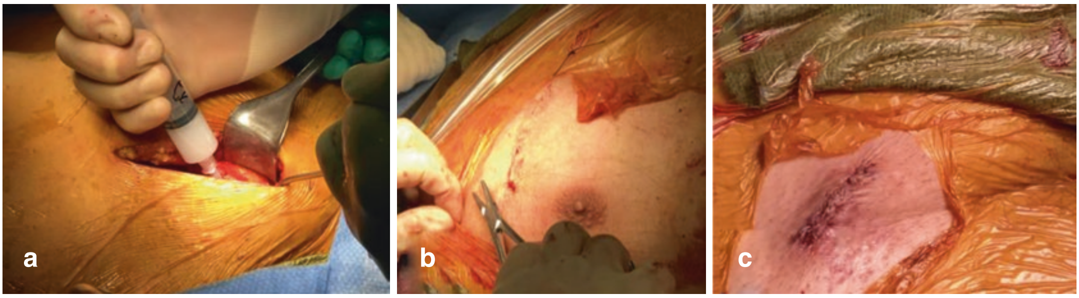

Fig. 21.23 Illustrations of the closure process for minimally invasive aortic valve surgery. (**a**) Injection of liposomal bupivacaine (EXPAREL) for post-operative analgesia. (**b**) Skin closure of the right anterior mini-thoracotomy incision. (**c**) Groin incision after closure

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