OFF-PUMP CABG

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A. POSITIONING THE HEART

The key step for the success of off-pump coronary artery bypass (OPCAB) surgery is the stable visualization of the target coronary artery under acceptable circulation. If the target coronary artery cannot be visualized adequately, the operation may need to convert to on-pump surgery. In the anatomical position, only the main stem of the right coronary artery (RCA) can be approached. To visualize all other coronary arteries, various techniques and devices should be employed to provide optimal positioning to the heart. Achieving an optical operative field requires collaborative efforts between the cardiac surgeon and the anesthesia specialist, and they must work together to maintain stable circulation for the patient during the anastomosis to ensure a successful OPCAB surgery.

1. Pericardial Sutures and Device-Free Techniques

Before the development of stabilization devices, deep pericardial sutures were used to position the beating heart. Two main suture techniques have been identified: the single suture technique and the Lima stitch. In the single suture technique, a single deep pericardial traction suture is placed from the inferior vena cava (IVC) to two-thirds of the way to the left lower pulmonary vein, as posteriorly as possible. A snare is used over this deep suture to prevent epicardial injury. By elevating the base of the heart with this deep suture, the lower wall of the left ventricle (LV) is exposed (Figures 6.1 and 6.2). In the other technique known as the Lima stitch, four deep sutures are placed on the posterior pericardium: one at the junction of the pericardium and the left upper pulmonary vein, one at the junction of the pericardium and the left lower pulmonary vein, one in the middle of the pericardium between the left lower pulmonary vein and the IVC, and finally, one just above the IVC (Figure 6.3). The position of the patient is crucial for appropriate access to the target artery during this process. The table is adjusted to Trendelenburg position for access to inferior regions (PD; posterodescending), rotated to the right for access to posterior regions (OM; obtuse margin and PL; posterolateral), and placed horizontally for access to anterior regions. The target anastomotic area is, then, stabilized with stabilization methods.

During the placement of deep pericardial sutures, it is of utmost importance not to go too deep into the tissues. The suture can cause serious bleeding from major vessels in the posterior mediastinum, such as pulmonary veins, or damage the esophagus. To prevent these serious complications, the suture must be passed over the posterior pericardium twice. Initially, the suture should be passed superficially, and an assistant should pull the thread to create a convex shape, away from the structure of the pericardium. Then, the surgeon should pass the thread more deeply through the pericardium.

The technique known as Lima stitch can be applied in different ways by surgeons to achieve a better optical anastomotic area and maintain the hemodynamic status of patients. Once the heart is displaced for access to the posterior and inferior regions, there is a high likelihood of compression in the right ventricle (RV), leading to potential disruption of RV diastolic filling and hemodynamic instability.

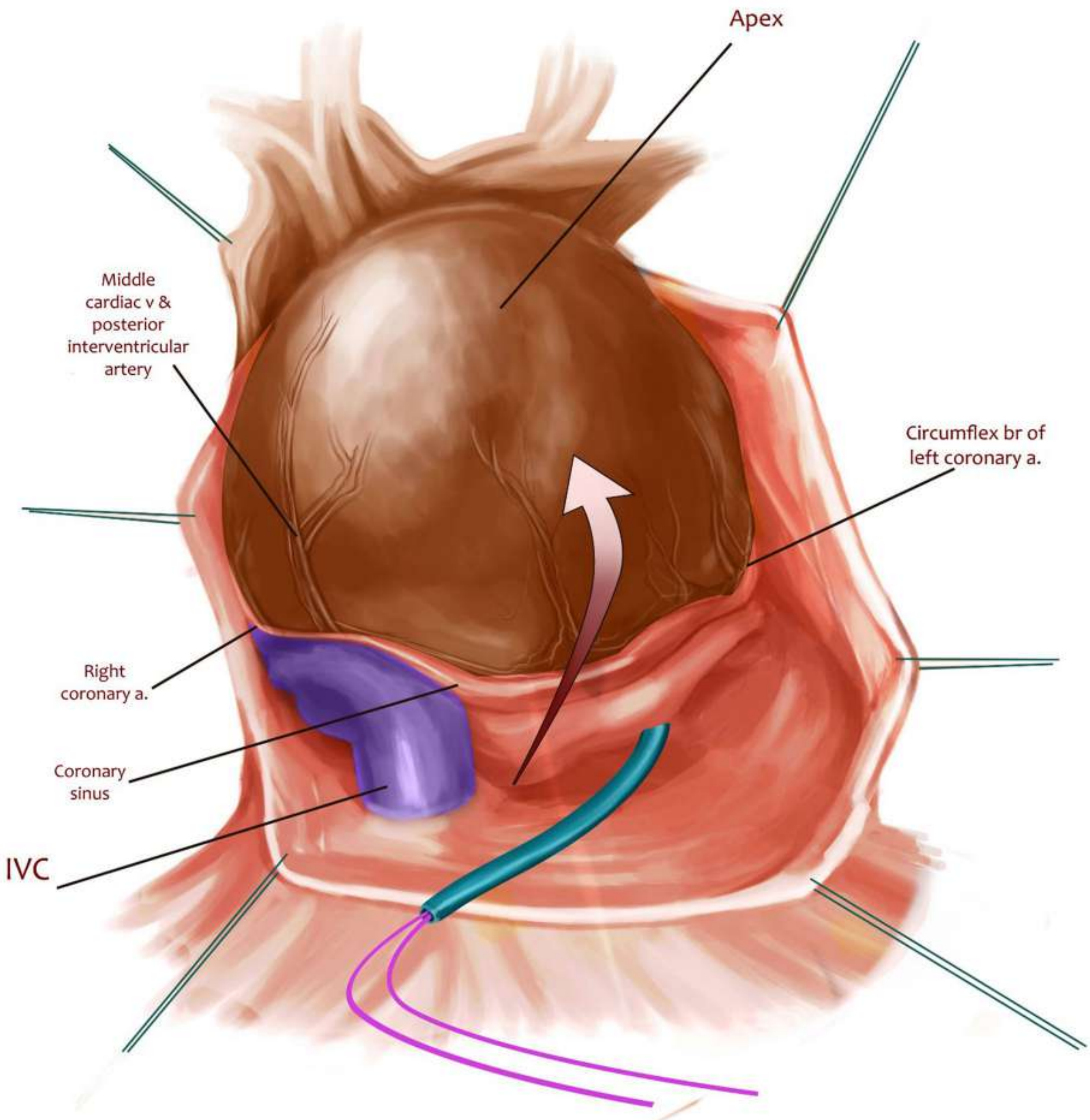

Figure 6.1. Deep pericardial stitches can be passed to bring the apex of the heart out of the thoracic cavity. To prevent damage to the moving heart by sutures, a snare should be used.
IVC: Inferior vena cava.

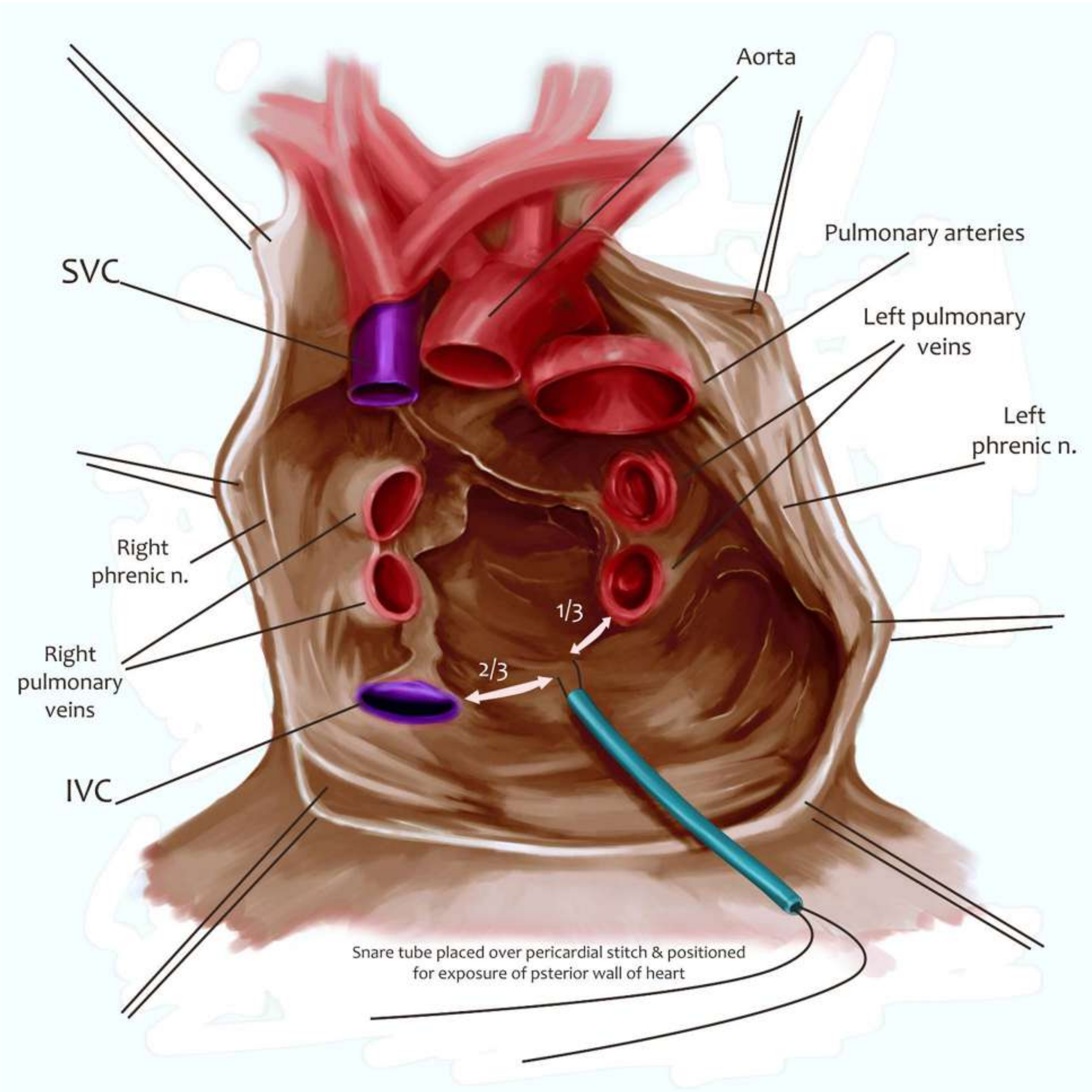

Figure 6.2. The placed suture should be positioned in the area shown in the figure, between the IVC and the left lower pulmonary vein.

SVC: Superior vena cava; IVC: Inferior vena cava.

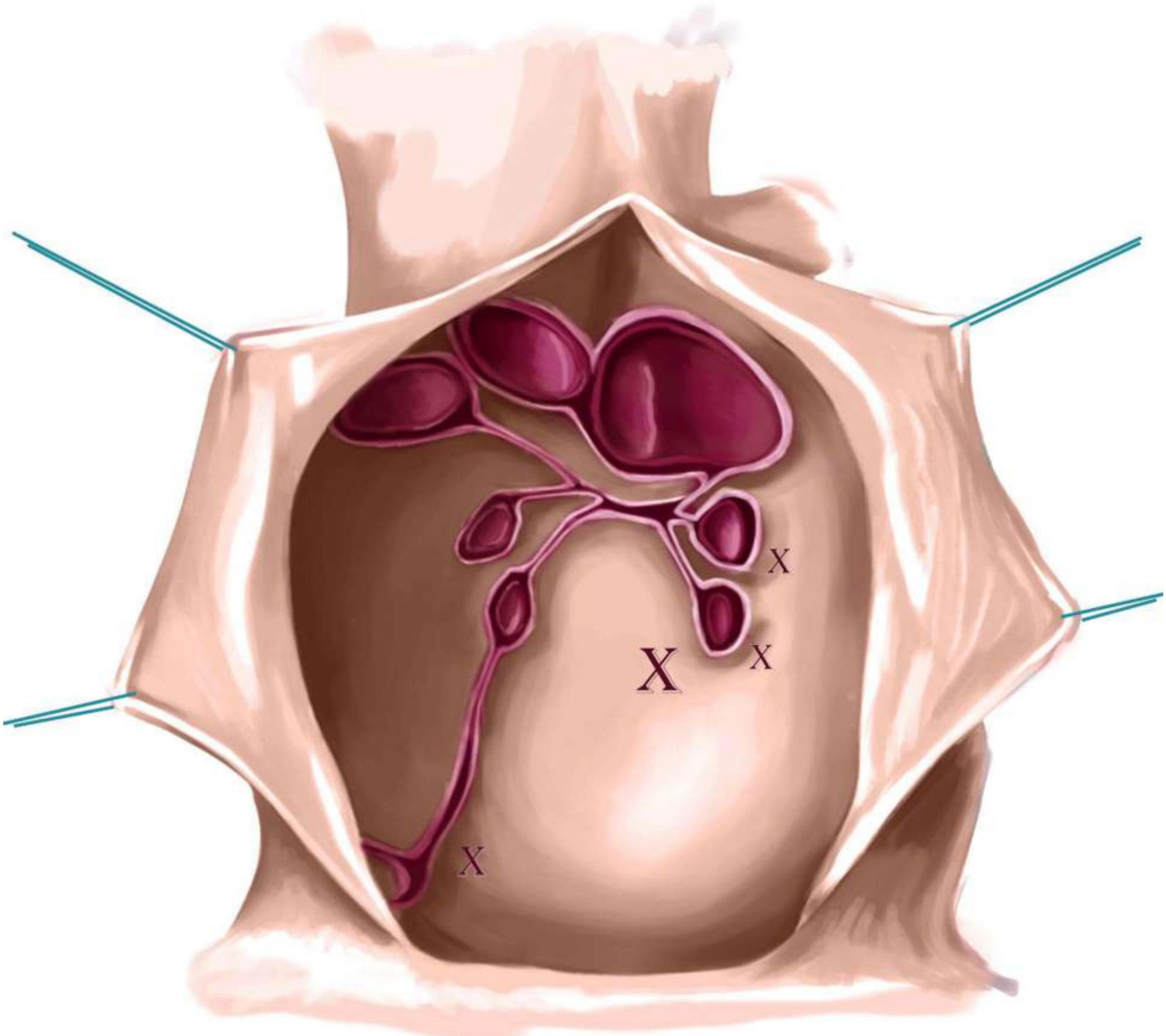

Figure 6.3. In a pericardial suture technique for left internal thoracic artery anastomosis, four deep stitches are placed on the posterior pericardium: one at the point where the pericardium joins the left upper pulmonary vein, one at the point where the pericardium joins the left lower pulmonary vein, one in the middle region of the pericardium between the left lower pulmonary vein and the IVC, and finally, one just above the IVC.

IVC: Inferior vena cava.

2. Apical Vacuum Devices

The development of deep pericardial suture techniques for exposing different coronary regions has significantly contributed to the increased use of OPCAB surgery. However, with the introduction of apical vacuum devices like Starfish® (Medtronic, Inc., MN, USA) and X-pose® (MAQUE, CA, USA), the utilization of these devices has grown. The manipulation of these devices is easy, and their functions are highly reliable. Apical vacuum devices are applied to the apex of the heart to expose the target coronary artery and are used to elevate and rotate the LV to the midline. The vacuum pressure level typically needed to maintain the position of the heart ranges between 200 and 250 mmHg. Patient positioning adjustments, such as Trendelenburg, right, and left rotation, may be necessary to expose the target artery. Opening the right pleura facilitates heart positioning, thereby reducing the likelihood of ventricular compression. However, accidental pulling during heart positioning with vacuum-type devices can lead to the tearing of the epicardium and the fat tissue around the heart apex, potentially causing bleeding complications, although severe bleeding rarely occurs. Deep pericardial sutures and apical vacuum devices are safe and effective methods for exposing the coronary artery in OPCAB surgery. It has been shown that there is less hemodynamic disturbance during the use of apical vacuum devices compared to deep pericardial sutures.

B. MYOCARDIAL STABILIZATION

Off-pump coronary artery bypass grafting (CABG) involves microsurgery on a beating heart. Technical errors in microstitches on small vessels can lead to graft stenosis and occlusion. Studies on human performance modeling have shown that experienced surgeons with high-power magnifying glasses have a technical error range of 0.1 to 0.2 mm. Assuming a surgeon is working on a coronary artery with a diameter of 1 to 2 mm, the stitching error can increase up to 20%. The amount of movement outside the anastomotic site is directly related to the size of the anastomotic opening. If the remaining movement is acceptable for the surgeon to make precise stitches, it enhances the quality of the anastomosis. Excessive movement, however, is thought to dramatically decrease the expected graft patency. The skill of the surgeon is a crucial factor for graft patency, making surgical experience and stabilization key to successful OPCAB surgery.

1. Vacuum-Assisted Stabilizers

In 1996, Borst et al. developed the Octopus® tissue stabilizer, which immobilizes the epicardium using a vacuum device. With the assistance of the Octopus® tissue stabilizer, OPCAB surgery became much more accessible, evolving into a simple and widespread method in the late 1990s. Subsequently, various types of vacuum-assisted stabilizers have been developed. Vacuum-assisted mechanical stabilization reduces movement by 85% during one cardiac cycle, making anastomosis significantly easier.

2. Stabilization with Tapes, Snares, and Stitches

Before the era of vacuum-assisted stabilization, tapes, snares, and stitches were used to stabilize the coronary anastomotic area. The effects of tissue stabilization depend on local factors, such as fat accumulation and the tortuosity of the target coronary artery in the anastomotic area. Therefore, additional stabilization can be achieved by pulling with a few stitches around the coronary anastomotic area.

C. BLOODLESS ENVIRONMENT

1. Coronary Occlusion

Simple coronary artery occlusion is a commonly used surgical technique during distal anastomosis. Although, theoretically, simple occlusion may harm the myocardium, it can be easily used, even in surgical areas where visualization is difficult. Simple occlusion is often preferred over coronary shunt techniques, as it provides better visualization of the coronary arteriotomy site. Various techniques have been introduced to stop bleeding in the anastomotic area, such as direct coronary clamping, snaring with elastic silicone loops, and intraluminal shunt use (Figure 6.4).

2. Coronary Artery Intraluminal Shunt

Temporary coronary occlusion is an easy way to obtain an optimal operating field without the need

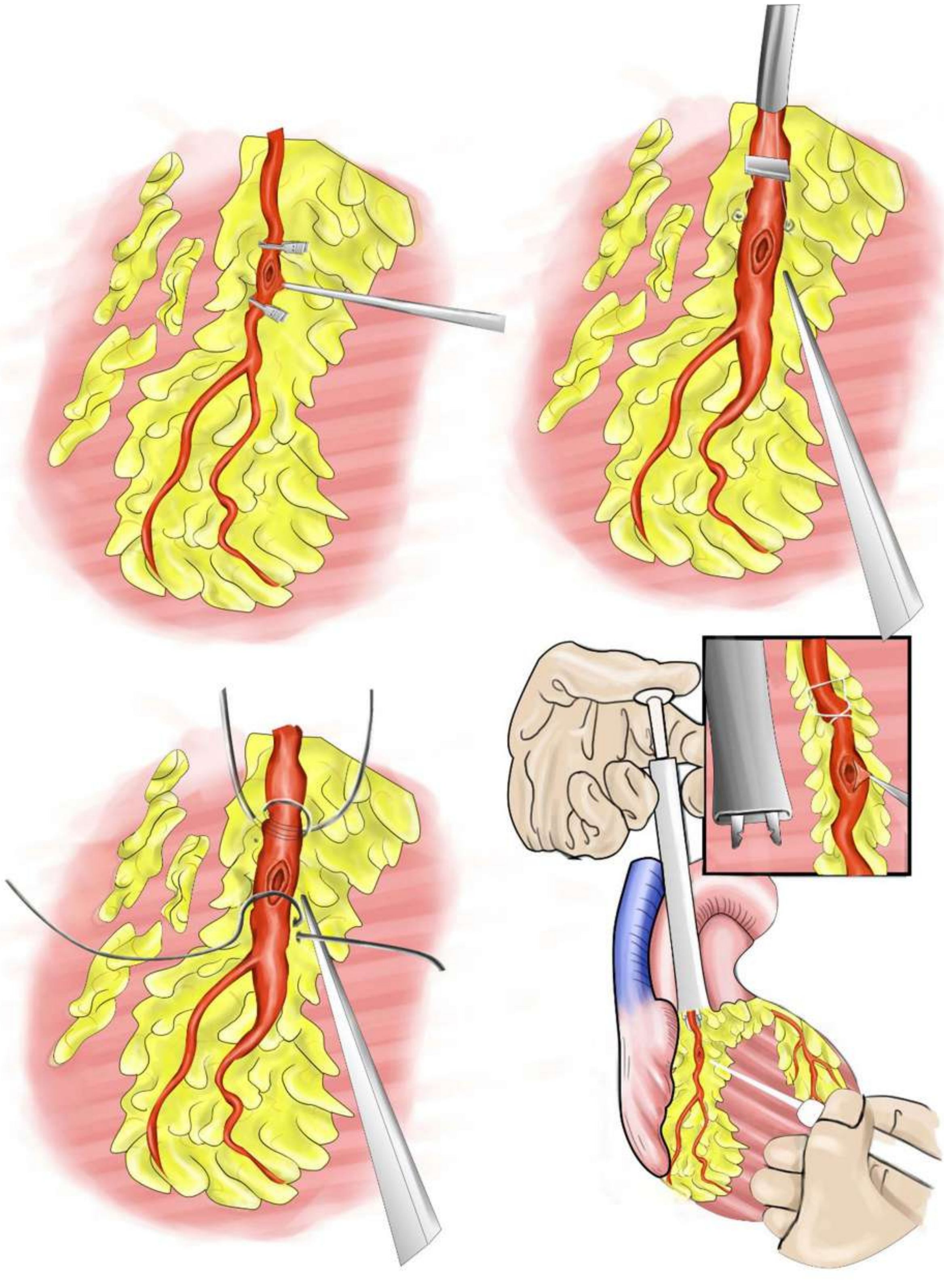

Figure 6.4. Various techniques, including direct coronary clamping, pulling with elastic silicone air cushions, and temporary clipping, are introduced to stop bleeding in the anastomotic area, alongside the simple coronary occlusion technique.

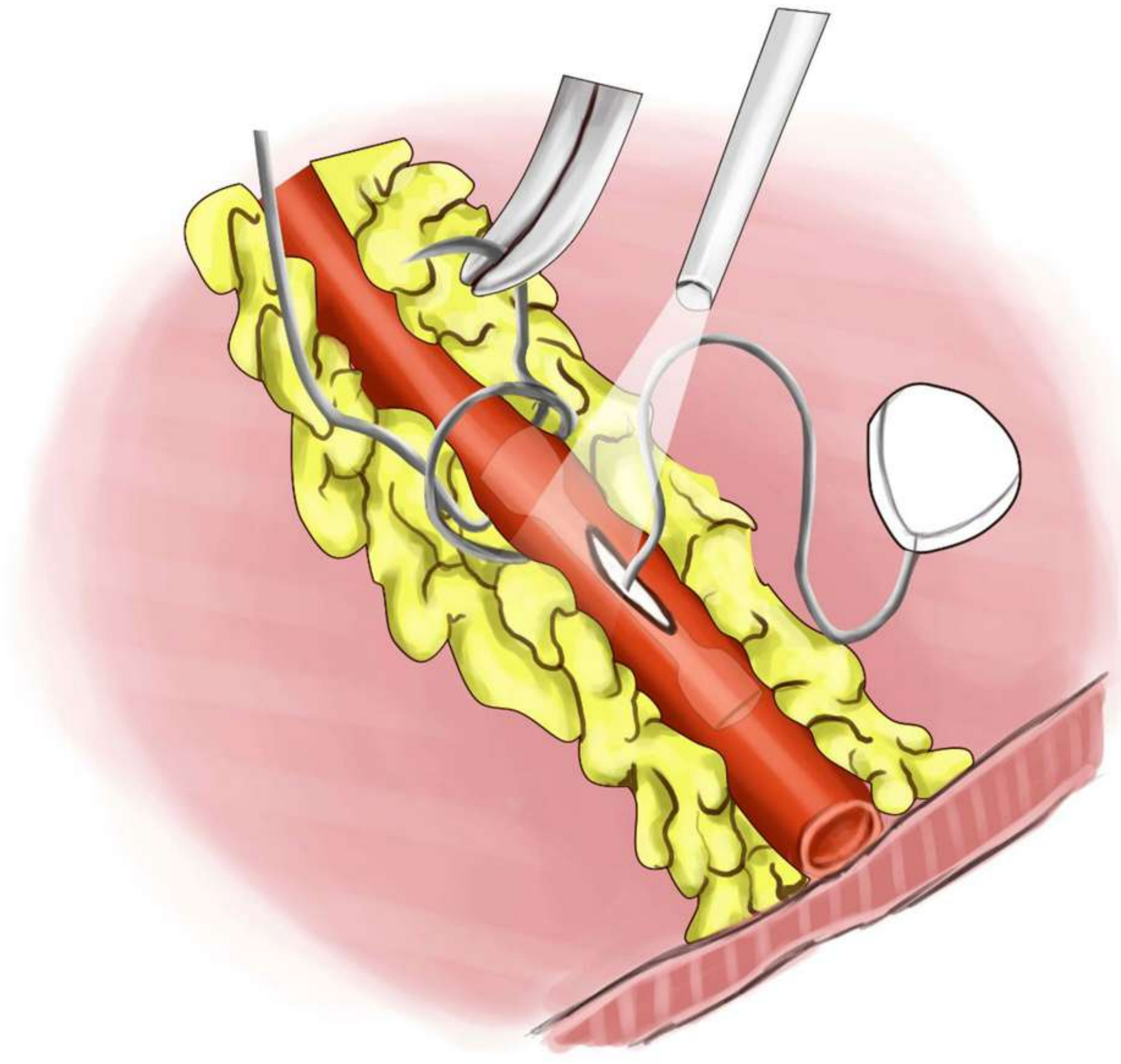

Figure 6.5. Intracoronary shunt is a commonly used method. It reduces bleeding, improves visibility, and allows continuous coronary blood flow. Additionally, it decreases the likelihood of passing stitches through the posterior wall.

for intervention. The use of intraluminal shunts has been shown to reduce acute ischemia, preserve LV function, and increase early graft patency compared to the simple coronary occlusion technique during CABG. The intraluminal shunt consists of a tube and a suture holding it from the middle. The proximal and distal ends of the shunt tube are slightly wider to fit into the inner lumen of the coronary artery. After opening the target coronary artery, the proximal and distal ends of the intraluminal shunt are placed inside the coronary artery. The flow of blood through the tube should be controlled, when the tube is inserted proximally. Intraluminal shunts provide both hemostasis and coronary perfusion.

Intraluminal shunts are safe, easy to use, and highly beneficial. However, mishandling the device can lead to serious problems. A large shunt tube may injure the coronary endothelium and dissect the coronary artery and arterial graft. Excessive use of the blower during proximal anastomosis can lead to the development of brain embolism. To avoid dry conditions, normal saline should be sprayed while blowing carbon dioxide (CO_2) (Figure 6.5).

3. Blowers

Sometimes, minimal bleeding from the coronary artery and surrounding tissues during both coronary artery occlusion and exploration can complicate the surgical view during anastomosis. The CO_2 blowers play a critical role in achieving an optimal surgical field during anastomosis. Of note, CO_2 has approximately 30 times higher solubility in blood than air, making it logical to use CO_2 to clean a bloody surgical field. The likelihood of CO_2 causing coronary air embolism and brain microembolisms is low. High-flow CO_2 blowers can injure the coronary artery endothelium, even dissecting the coronary artery and arterial graft. Excessive use of blowers during proximal anastomosis can lead to the development of brain embolism. To avoid dry conditions, normal saline should be sprayed while blowing CO_2. Consequently, CO_2 blowers should only be applied during the time needed to pass the suture needle through the coronary artery, graft, and aortic wall.

TIPS & PITFALLS

Evaluation and Troubleshooting in Off-Pump CABG

- Preoperative phase:

- Continuous evaluation of the patient is essential once the operation begins.
- Adequate preparation for all possible scenarios that may arise preoperatively should be ensured, and all surgical instruments should be readily accessible.
- The cardiopulmonary bypass machine must be kept ready in the operating room, and an experienced perfusionist should be readily available for emergency interventions.
- Arrythmias developing during graft preparation should be visually evaluated, and any hemodynamic instability occurring at this stage should be promptly assessed, with necessary interventions (fluid replacement, antiarrhythmics, vasopressors) performed rapidly to restore stability.
- During the placement of pericardial stitches, avoiding deep stitches is crucial, with special attention to preventing vagus nerve damage.
- After pericardial stitches, vacuum-assisted positioning, and maneuvers of the operating table, it must be ensured that the heart is in a stable hemodynamic condition.

TROUBLESHOOTING

- If hemodynamic stability cannot be achieved, the heart should be returned to its normal position, and different maneuvers should be attempted until adequate perfusion to the heart is ensured.
- The adequacy of the vacuum feature of the vacuum-assisted stabilizer should be checked, ensuring that excessive vacuum is not applied to avoid surface injuries to the heart.
- Extra sensitivity should be given to surrounding tissues during the use of clamps and elastic tapes to cut off the coronary blood flow.
- Superficial interventions may cause tears and extra bleeding, while sutures and clamping deeper than necessary may lead to ventricular injuries and undesired fatal complications.

- Coronary shunts can be used to avoid ischemic complications. The diameter of the coronary artery is crucial during the shunt use.
- Large shunts may cause injuries to the coronary artery and serious errors in the heel and nose stitches of the anastomosis.
- Shunt usage is essential in arteriotomies of an appropriate size. Large arteriotomies can reduce the anastomotic opening, while small arteriotomies can complicate shunt placement and lead to inevitable coronary artery injuries.
- Shunts should be removed slowly and delicately. After each anastomosis, a waiting period should be observed to ensure sufficient perfusion and graft function before starting heart positioning for the next anastomosis.
- Vacuum devices should be carefully manipulated after each anastomosis, ensuring they are removed from the operative site without causing damage to the anastomosis.

TROUBLESHOOTING SCENARIOS

- Defect in the coronary artery wall during anastomosis. Serious technical error may have occurred. Enter the pump, repair the defect thoroughly!
- Ventricular fibrillation occurred during positioning or anastomosis. Normal hemodynamics were restored with electrical defibrillation. Enter the pump for the beating heart; when forced, you are likely to experience fibrillation again shortly.
- Shunt placed, no visibility, and bleeding continues. Shunt size is not appropriate; re-evaluate the shunt size appropriately.