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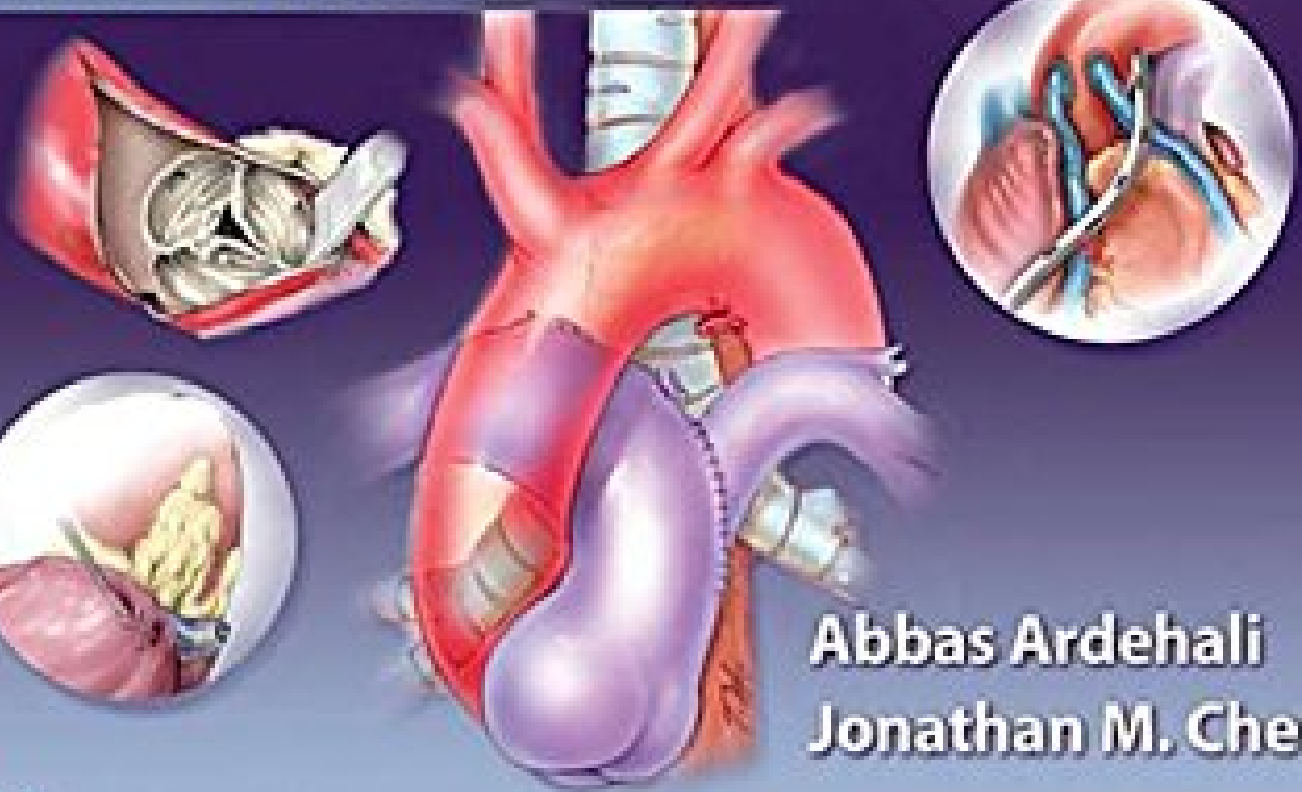
Khonsari's CARDIAC SURGERY

Safeguards and Pitfalls in Operative Technique

FIFTH EDITION



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Dedication

To our families:
Mitra, Leila, and Sara Ardehali
and
Abbie, Maddie, and Atlas Chen

Foreword

The concept of *Cardiac Surgery: Safeguards and Pitfalls in Cardiac Surgery* came to me over 35 years ago. I wanted to provide a tool to help surgical residents master the techniques of cardiac surgery while avoiding the pitfalls that often result in suboptimal or even fatal outcomes. After five years of preparation, the work was completed and published in late 1987. Many prominent cardiac surgeons from Europe and the United States reviewed each chapter and made useful suggestions, thus benefitting the work with their vast experiences.

The book would not have been completed without the support and invaluable encouragement of the late Professor Gerry Brom of Leiden. The superb "telling" illustrations by Joanie Livermore and Timothy Hengst have been the hallmark of the work. The success of the book is reflected in the present (fifth) edition and the fact that it has been translated into Portuguese, Japanese, and Chinese. It has been gratifying to visit operating rooms in many countries and see a copy of the book or photocopies of its various chapters there. My partner and colleague of close to 30 years, Dr. Colleen Sintek, was my coauthor on the second, third, and fourth editions, and I am very much indebted to her and grateful for her support.

My good fortune does not end here. For this fifth edition, I have been blessed to have Dr. Abbas Ardehali, professor of surgery, David Geffen School of Medicine at University of California, Los Angeles, an esteemed friend and colleague, accept the baton of responsibility to ensure the continued success of the book. Dr. Jonathan Chen, professor of surgery and chief of pediatric cardiovascular surgery at University of Washington, Seattle, has been gracious to edit and update the Congenital section. I am very impressed with their contributions and am grateful for their efforts in bringing the fifth edition of *Cardiac Surgery: Safeguards and Pitfalls in Cardiac Surgery* to fruition.

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Preface

K*honsari's Cardiac Surgery: Safeguards and Pitfalls in Operative Technique* is a unique book in the field of cardiac surgery. It details the important technical aspects of cardiac surgery in a concise, readable, and illustrative format. It also highlights technical misadventures and offers preventive and corrective measures. It serves as a great resource for the novice and/or trainee as well as the seasoned surgeon.

The popularity of this book since the first edition has been due to Dr. Khonsari's unmatched surgical intuition, wisdom, judgment, and attention to details, as is evident throughout this book. Illustrative and detailed figures have been and continue to be an important feature that emphasizes salient points. Dr. Sintek's collaboration on the previous two editions has only enhanced these qualities of this popular book. We, the present editors, have tried very hard to maintain the character of this book: emphasizing technical aspects of cardiac surgery, highlighting pitfalls, striving for brevity, and using clear illustrations to convey the message to the readers.

Organizationally, the first two sections remain dedicated to adult cardiac surgery, while the third section covers pediatric cardiac surgery. All chapters have been updated, new illustrations have been added, and some of the illustrations have been colorized for greater clarity. Additionally, new topics have been added to reflect the advances in the field: endovascular procedures, transcatheter aortic valve replacement, new approaches to the Norwood reconstruction, repair of Ebstein anomaly, and alternative anatomic repairs of congenitally corrected transposition.

The format of this book follows the previous editions: the technical pitfalls are denoted by a hazard sign  . The mechanism of technical errors and the techniques to prevent and correct these errors are emphasized. Important points are highlighted by special Nota Bene  notations.

Khonsari's Cardiac Surgery: Safeguards and Pitfalls in Operative Technique has long been considered a great reference text in technical aspects of cardiac surgery. We have worked hard to maintain the core strengths of this book: a concise, illustrative, and focused description of techniques in cardiac surgery. We believe that with the many improvements implemented in this fifth edition, it will continue to be a valuable resource for cardiac surgery trainees and senior surgeons alike.

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Los Angeles, California
June 2016

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June 2016

Acknowledgments

First and foremost, Dr. Chen and I would like to thank Dr. Khonsari and Dr. Sintek for their many contributions to the field of cardiac surgery and the legacy they have left with this book. I am privileged to have been trained by them, and I remain grateful for the imparted wisdom, support, and importantly their friendship. I would also like to thank Dr. Peyman Benharash of the Division of Cardiac Surgery at UCLA for his contributions to endovascular procedure topics and many helpful suggestions in other chapters.

Finally, we would like to thank the editorial staff at Wolters Kluwer, particularly Brendan Huffman and Keith Donnellan, for their assistance and dedication. We also would like to thank Lik Kwong and Carolina Hrejsa from BodyScientific for their tireless work to create and update the artwork in this new edition. We believe that the fifth edition carries on the tradition of its predecessors while delivering the most current and concise reference book on techniques and pitfalls in the field of cardiac surgery.

Abbas Ardehali

1
Surgical Approaches to the Heart and Great Vessels

PRIMARY MEDIAN STERNOTOMY

Median sternotomy remains the most widely used incision in cardiac surgery because it provides excellent exposure for most surgeries involving the heart and great vessels.

Technique

The skin incision normally extends from just below the suprasternal notch to the tip of the xiphoid process. A saw with a vertical blade is most commonly used to divide the sternum. In young infants, the sternum is divided with heavy scissors. An oscillating saw is used for repeat sternotomies and some primary surgeries through limited skin incisions. Its use requires that the surgeon develop a "feel" for when the blade has penetrated the posterior table of the sternum (see Repeat Sternotomy section).

Bleeding

A small vein is usually evident running transversely in the suprasternal notch. At times, however, it may be large and engorged, particularly in patients with elevated right heart pressure. Excessive bleeding may occur if this vein is inadvertently injured. It is important to be aware of its presence and to coagulate it (if tiny) or to occlude it with a metal clip. If the vein has been cut and its ends have retracted, thereby making hemostasis difficult, control of bleeding can be gained by packing the suprasternal notch area and proceeding with the sternotomy. After the two sides of the sternum have been spread apart, the sites of bleeding can be easily identified and controlled.

Sternal Infection

Not only is dissection of the suprasternal notch unnecessary, but it can also open up tissue planes in the neck. Tracheostomy is now rarely necessary but always remains a possibility. Whenever tracheostomy is performed, a separate incision is kept as high in the neck as possible so that a superficial tracheostomy wound infection does not spread into the suprasternal notch and eventually into the mediastinum, leading to wound complications and mediastinitis.

Entry into the Peritoneal Cavity

During the division of the linea alba or the lower part of the pericardium, the peritoneal cavity may be entered. The opening should be closed immediately to prevent any spillage of blood or cold saline used for topical cooling into the peritoneal cavity, which may promote postoperative ileus.

Asymmetric Division of the Sternum

The sternotomy should be in the midline of the sternum. By dipping the thumb and index finger into the incision and spreading them against the lateral margins of the sternum into the intercostal spaces, the proper site for sternal splitting can be located and marked by an electrocautery on the periosteum. Unequal division may leave one side of the sternum too narrow and allow the closure wires to cut through the narrower segments of the bone, leading to an increased incidence of sternal dehiscence. Similarly, the costochondral junction may be damaged (Fig. 1.1).

Pneumothorax and Hemothorax

The anesthesiologist is always asked to deflate the lungs while the surgeon is using the sternal saw so that the pleural cavities can be kept intact. This is particularly important in patients with chronic obstructive pulmonary

disease and hyperinflated lungs. Occasionally, however, the pleural cavities are opened by the sternal saw or during dissection of the thymus and pericardium. If the opening is small and no fluid has entered the pleural cavity, at the close of the procedure, the tip of the mediastinal chest tube may be introduced for 2 to 3 cm into the pleural defect. The pleura may be opened fully, particularly in patients undergoing harvesting of internal thoracic arteries. In these cases, a separate chest tube is inserted subcostally over the lateral aspect of the diaphragm for drainage of fluid and blood and evacuation of air.

Use of Bone Wax

Excessive use of bone wax to control bleeding from the sternal marrow should be avoided. It can be associated with increased rates of wound infection, impaired wound

healing, and, most serious of all, wax embolization to the lungs. However, the use of small amounts of bone wax is an effective tool to control bleeding from sternal edges. We have found that vancomycin paste (mixing of vancomycin powder with 2.5 ml of saline) is an effective agent for sternal bone marrow oozing, with possible antimicrobial properties.

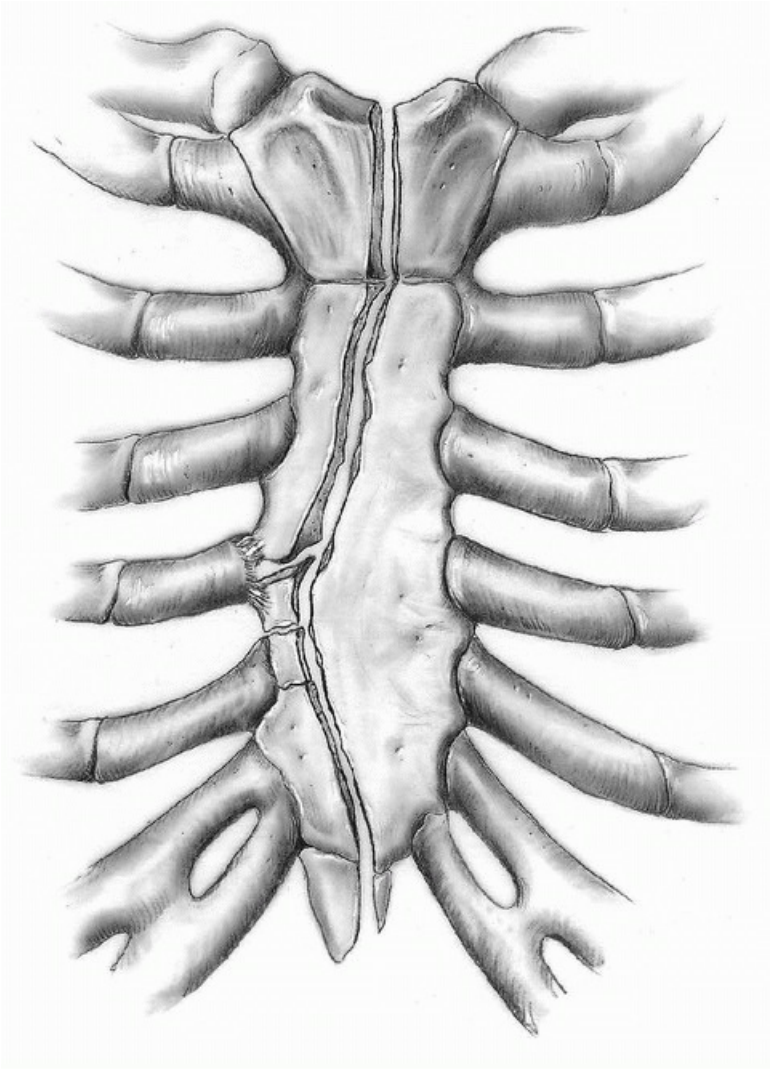

FIG. 1.1 Fracture resulting from improper division of the sternum.

Brachial Plexus Injury

Brachial plexus injury has been associated with median sternotomy. Stretching of the plexus by hyperabduction of the arm and compression of the nerve trunks between the clavicle and first rib during sternal retraction has been implicated as a cause of injury. Introduction of a Swan-Ganz catheter through the internal jugular vein can

injure the brachial plexus, either directly by the introducer itself or indirectly by the formation of a hematoma in the vicinity. The most serious cause of brachial plexus injury is fracture of the first rib (Fig. 1.2). The sternal retractor should be placed with its crossbar superiorly so that the blades spread apart the lower third of the sternal edges. It is then opened gradually in a stepwise manner (one to two turns at a time) to prevent fractures of the first rib or sternum (Fig. 1.3A). If for some reason the crossbar of the retractor is to be placed inferiorly, it is important for the blades to be in the lower part of the incision. Many surgeons use modified sternal retractors with two or three blades on either side, placing the crossbar inferiorly. These retractors are opened just enough to provide adequate exposure (Fig 1.3B).

Retractors (e.g., Favaloro) used in harvesting the internal thoracic artery can also cause brachial plexus injury. Therefore, sudden excessive upward pull on the retractor should be avoided. The surgeon should ensure good exposure by manipulating the operating room table and his or her headlight to minimize traction of the upper sternum. Moreover, when the proximal internal thoracic artery is freed, the degree of upper sternal retraction is reduced. These simple measures can often eliminate or reduce the incidence of brachial plexus injury.

Innominate Vein Injury

The innominate vein may be injured during dissection and division or resection of the thymus or its remnant, particularly when scarring is present from a previous surgery. The scar tissue on each side of the injured vein is dissected free. Brisk bleeding can then be controlled by simple suturing. In rare instances of severe damage to the vein, it is divided and its right end is suture ligated. The other end of the vein is left open for drainage of venous return from left internal jugular tributaries until the patient is ready to come off cardiopulmonary bypass when it is similarly suture ligated.

The innominate vein is a useful channel for an additional intravenous line, which can be used to monitor central venous pressure, particularly in infants and patients with poor peripheral veins. The catheter is introduced percutaneously into the center of a 7-0 Prolene purse-string suture buttressed with fine pericardial pledgets on the innominate vein. The purse-string suture must be tied snugly to prevent any bleeding after removal of the venous line. Sometimes, a large thymic vein can be used for the same purpose.

REPEAT STERNOTOMY

An increasing number of patients require surgical intervention a second, third, or even fourth and fifth time for replacement of prosthetic valves, definitive correction or revision of congenital heart defects, or repeat myocardial revascularization. Because it is anticipated that this trend will continue, all cardiac surgeons must acquire expertise in preoperative procedures. When making the skin incision, it is not always necessary to excise the previous scar unless it is gross and thick. The subcutaneous tissue is incised in the customary manner, and using electrocoagulation, the sternum is marked along the midline.

Technique

Previous wires or heavy nonabsorbable sutures are divided anteriorly but are not removed. They provide some resistance posteriorly to the oscillating saw, which helps

to prevent any possible right ventricular injury (Fig. 1.4, inset). Only limited, sharp dissection adequate for the placement of a small Army-Navy retractor can be safely carried out in the suprasternal notch or around the xiphoid process.

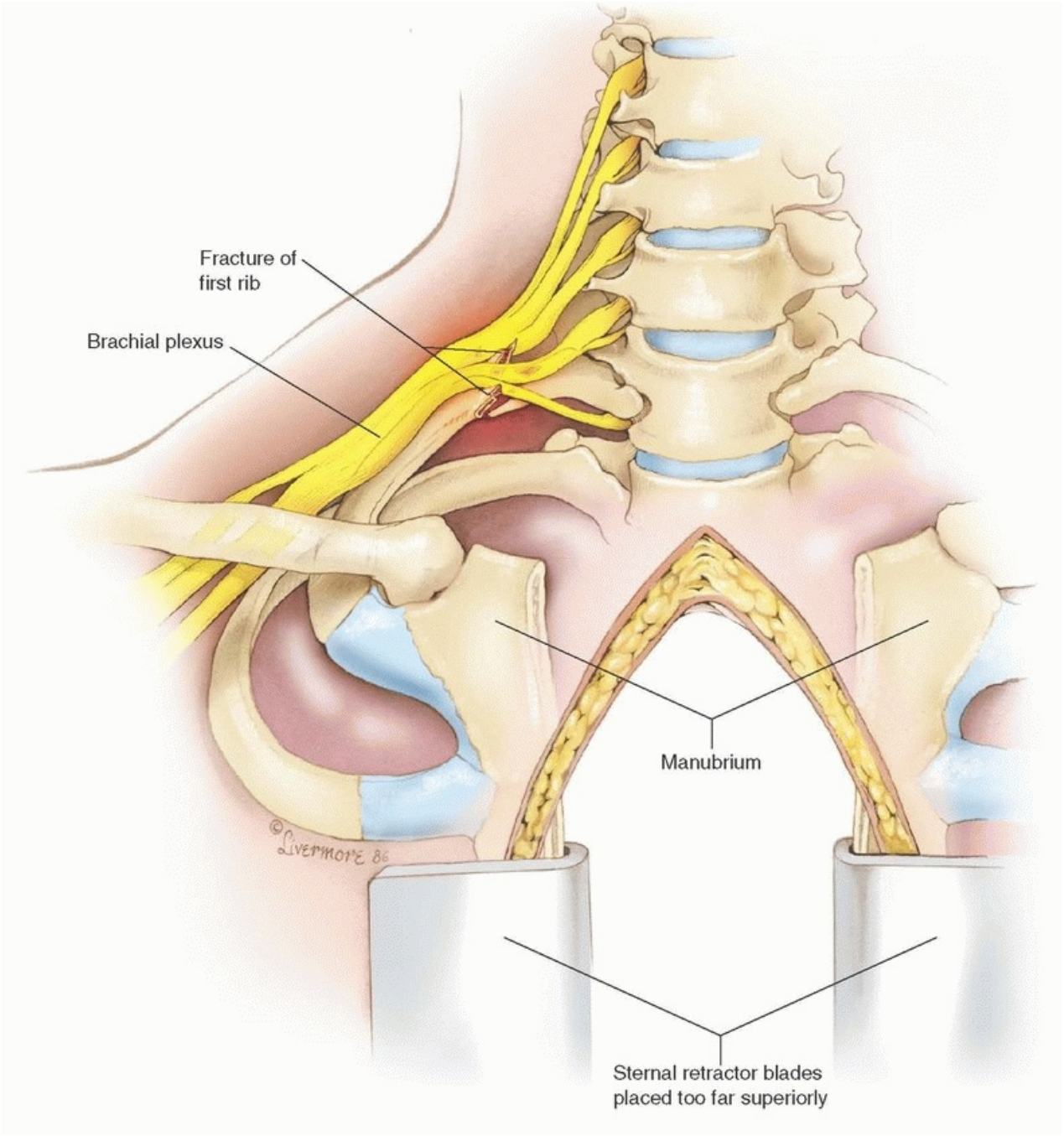

FIG. 1.2 Mechanism of a brachial plexus injury.

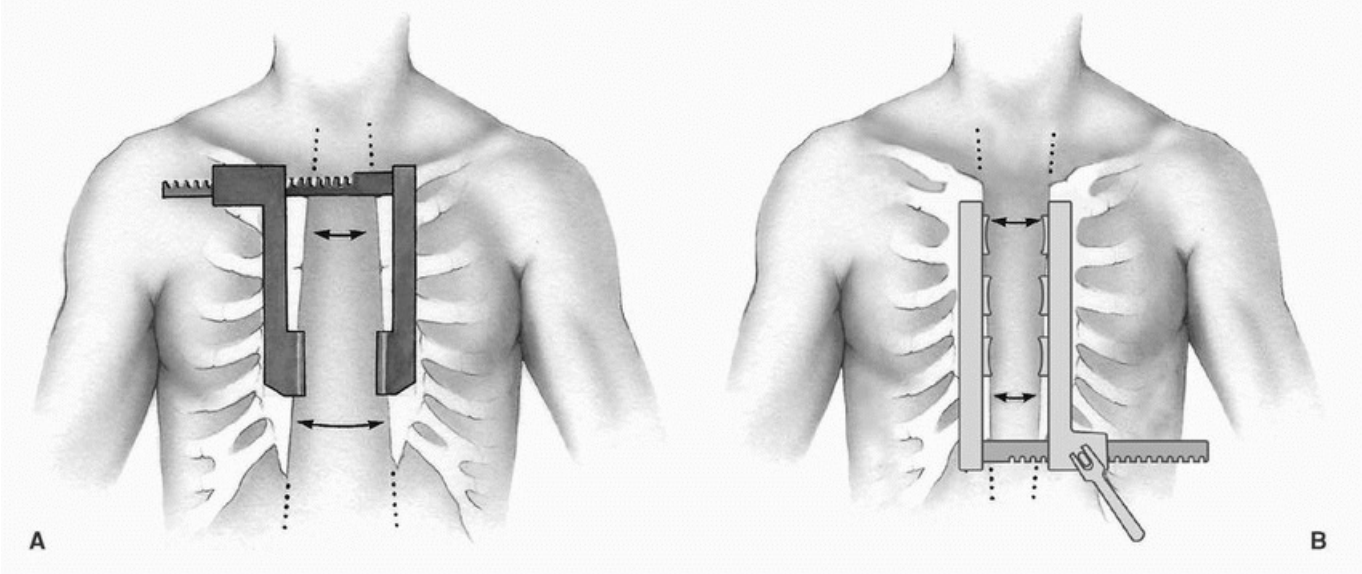

FIG. 1.3 A and **B:** Techniques for sternal retractor placement.

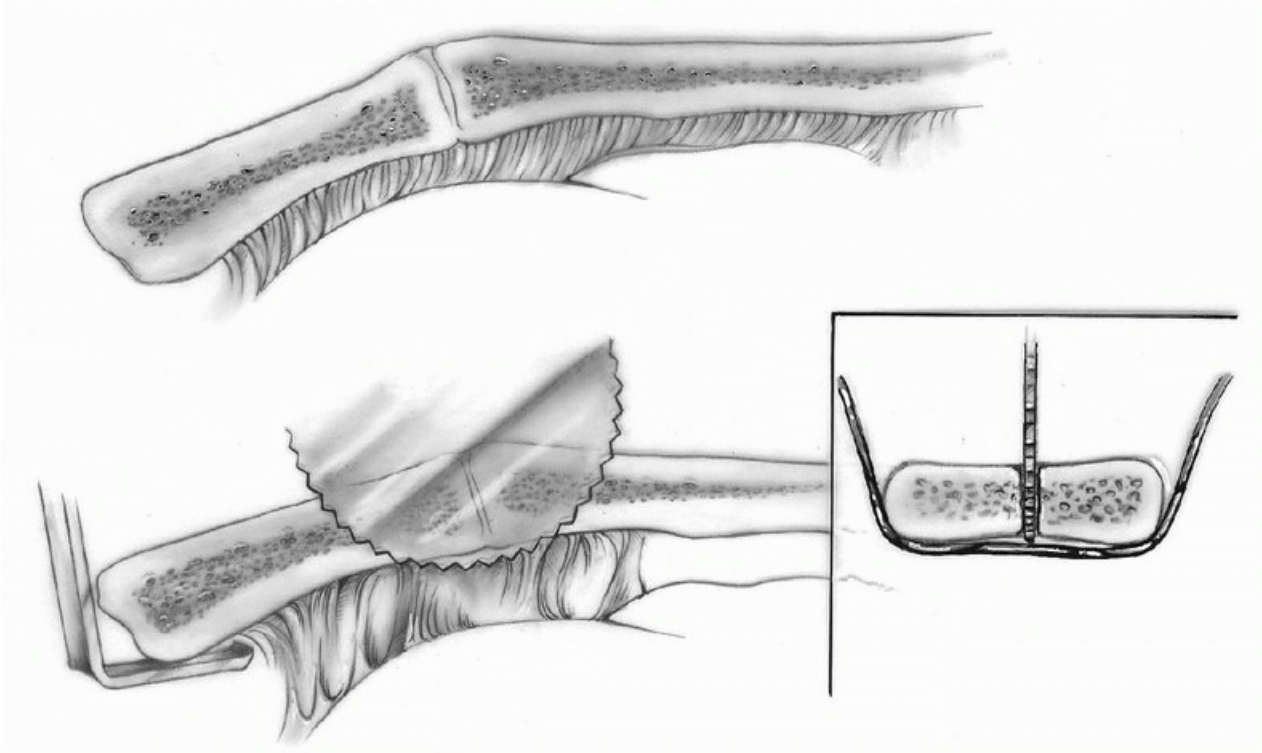

FIG. 1.4 Elevating the posterior table of the sternum to increase the distance between the saw blade and underlying structures.

Right Ventricular Injury

Blunt digital dissection behind the lower sternum should rarely be practiced in patients with a previous sternotomy because of possible injury to the friable right ventricular wall (Fig. 1.5).

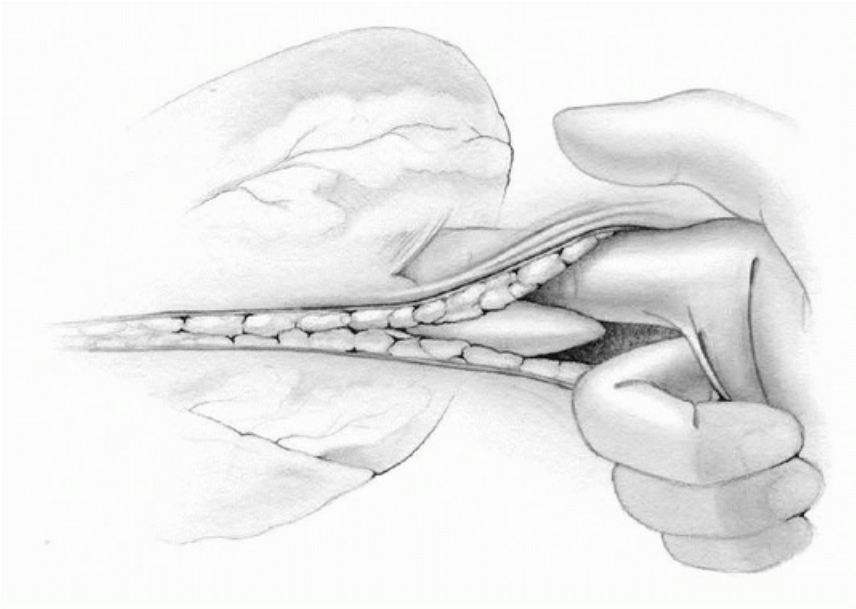

FIG. 1.5 Right ventricular injury caused by blunt digital dissection.

The sternum is raised by retractors at the suprasternal notch superiorly and at the xiphoid inferiorly during sternal division with an oscillating saw (Fig. 1.4). Small rake retractors are inserted into the marrow cavity on

each side of the sternal edge and gently lifted upward toward the ceiling, thereby making the adhesions between the retrosternum and the heart slightly taut and accessible for division with the cautery or scissors (Fig. 1.6).

A lateral chest radiograph often reveals the proximity of the right ventricle and ascending aorta to the undersurface of the sternum. However, a computed tomography scan will accurately identify the relation between the ascending aorta and the underside of the sternum. When the ascending aorta is noted to be adherent to the undersurface of the sternum, precautions must be taken before performing a sternotomy.

Before a sternotomy is attempted, a small transverse incision is made in the second or third right intercostal space. This allows a lateral approach for dissection to free the aorta from the undersurface of the sternum. After this has been accomplished, the sternum can be divided in the manner described for repeat surgery without risk of injury to the aorta (Fig. 1.7).

Our preference is femoral artery-femoral vein bypass and core cooling to 18°C before sternotomy (see Chapter 2). Cardiopulmonary bypass is then established, and the patient is cooled to 18°C to 20°C. Assisted venous drainage with a centrifugal pump or vacuum assist is useful. Aortic insufficiency owing to the presence of a bileaflet or a single-disc mechanical prosthesis or a disrupted aortic

bioprosthesis may result in left ventricular distension. An appropriately sized vent is placed into the apex of the left ventricle through a small left anterior thoracotomy as cardiopulmonary bypass is being initiated to protect the heart from overdistension (see Left Ventricular Apical Venting section in Chapter 4). Transesophageal echocardiography is always used to monitor left ventricular volume. If left ventricular distension occurs either at the initiation of bypass or when the heart begins to fibrillate, a vent is placed immediately.

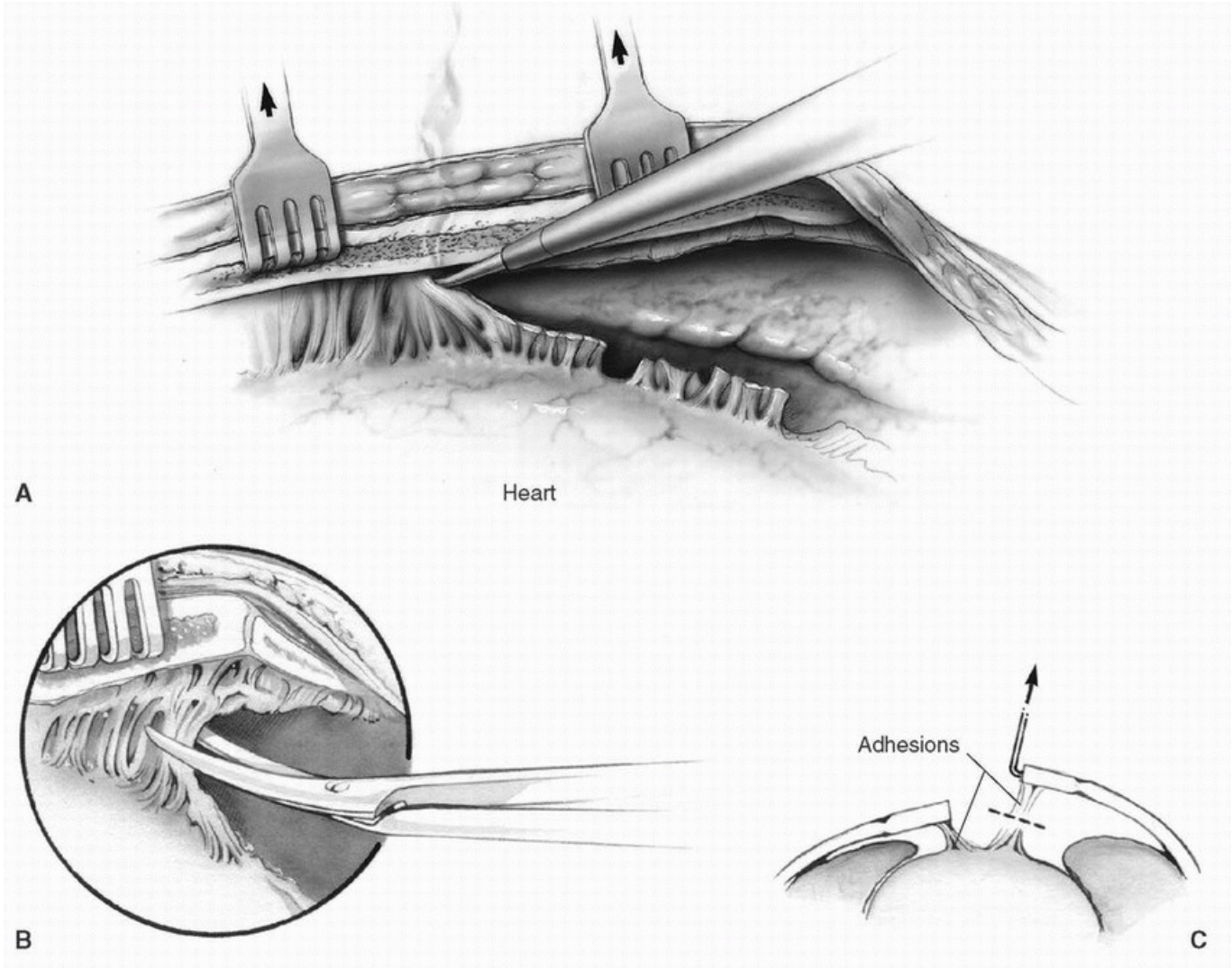

FIG. 1.6 A-C: Stepwise division of fibrous adhesions from the undersurface of the sternum.

If the sternotomy is uneventful, the patient is gradually rewarmed and the surgery is completed in the usual manner. Conversely, if the aorta is torn or disrupted, hypothermic arrest is instituted and the ascending aorta is repaired or replaced. The intended surgery is then resumed to its completion.

NB This precaution may appear to be a very major undertaking with its own possible serious complications. However, it is the only way to prevent catastrophic hemorrhage with a frequently fatal outcome. NB

NB Unanticipated Aortic Entry

When the possibility of aortic injury is not anticipated and the aorta is entered during sternotomy, towel clamps are used to reapproximate the sternal edges in an effort to tamponade the bleeding site. Direct pressure should be applied by an assistant surgeon while cardiopulmonary bypass is established expeditiously through the femoral artery and vein, as noted in the preceding text. NB

NB Division of the Posterior Table

The division of the posterior table of the sternum may be accomplished with heavy scissors under direct vision. This is facilitated by elevating the sternum slightly with a rake retractor. Such a maneuver is particularly important at the manubriosternal junction, where the manubrium takes a posterosuperior course (Fig. 1.4). NB

Fibrous adhesions to the undersurface of the sternum are mainly along the previous sternotomy. After dividing these fibrous adhesions with an electrocautery or scissors, the sternum is relatively free (Fig. 1.6). An adequate

dissection is carried out so that the sternal retractor can be safely positioned and slowly opened.

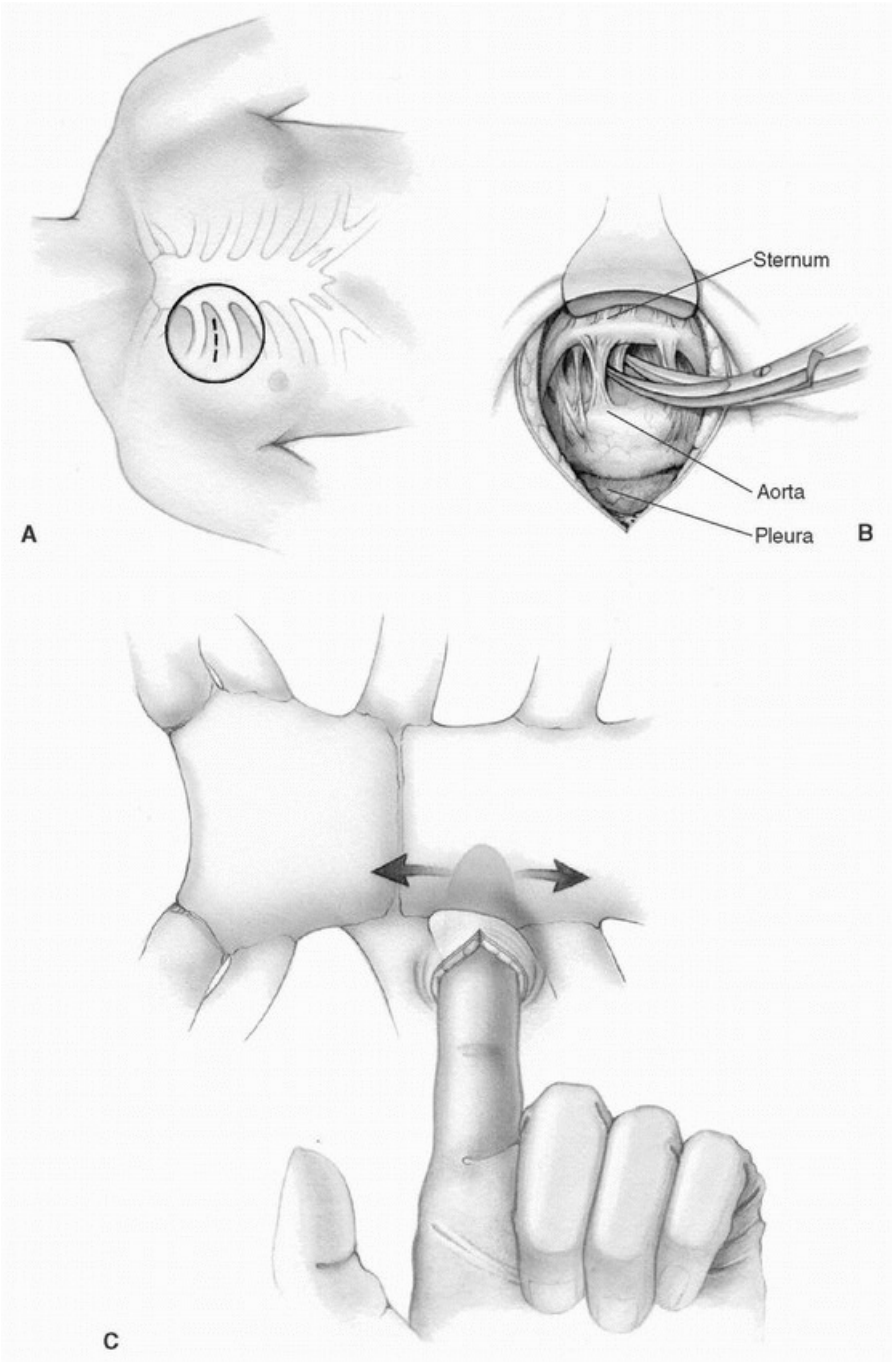

FIG. 1.7 A-C: Stepwise technique for separating the ascending aorta from the sternum in repeat procedures (see text).

By slow and careful sharp dissection along the right inferior border of the heart, the proper plane can be identified relatively easily. Some surgeons find that the use of the electrocautery blade on a low setting allows this dissection to be accomplished with less bleeding from the pericardial surfaces. The dissection can then be gradually carried upward, exposing the right atrium and aorta for cannulation in preparation for cardiopulmonary bypass.

Right Ventricular Tear

A small (Himmelstein) chest retractor can now be inserted and must be spread apart only slightly; an overzealous attempt to widen the sternal opening results in stretching of the right ventricular wall. Tearing of the right ventricle

because of saw injury or overstretching of the sternotomy is a life-threatening complication. The bleeding should

be controlled by direct pressure on the site while cardiopulmonary bypass is initiated as promptly as possible. With the right ventricle totally decompressed, the wound is repaired with multiple, fine pledgeted sutures (Fig. 1.8). In cases of saw injury, pressing the two sternal halves together and toward the heart may tamponade the bleeding while cannulation of the femoral vessels is accomplished.

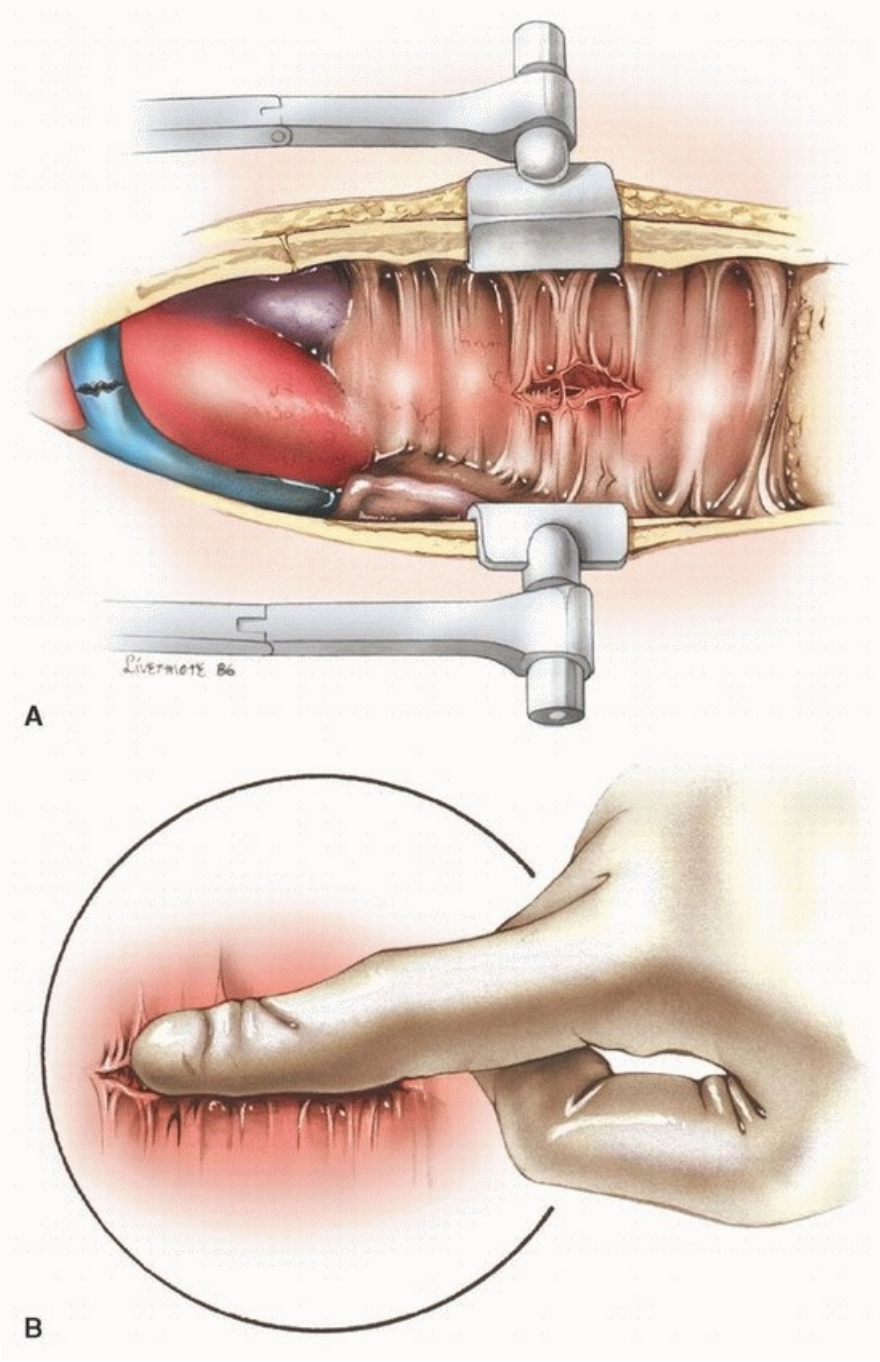

FIG. 1.8 A: Mechanism of a tear of the right ventricle and innominate vein in repeat procedures. **B:** Digital control of bleeding from the right ventricle.

Injury to Innominate Vein

In patients undergoing repeat sternotomies, the innominate vein is often adherent to the undersurface of the manubrium. It may be injured directly with the saw or torn as the sternal halves are being retracted (Fig. 1.8). In most cases, the bleeding can be controlled with digital pressure on the opening in the vein while the vein is carefully dissected free from the posterior aspect of both sides of the manubrium. If control of the bleeding cannot be rapidly secured, the two sternal halves should be pushed together with slight downward pressure by the assistant surgeon to minimize blood loss. Blood should be transfused as necessary and femoral arterial and venous cannulation obtained as quickly as possible. The innominate vein can then be dissected free and

repaired with 5-0 Prolene suture on cardiopulmonary bypass.

If the innominate vein injury is a complex tear or transection, repair may not be feasible. Then, the right side of

the vein may be oversewn immediately, but the left side should be allowed to bleed freely and the blood returned to the bypass circuit by a pump sucker during cardiopulmonary bypass.

NB Acute occlusion of venous drainage from the left subclavian and jugular veins during cardiopulmonary bypass may lead to central nervous system injury. The left-sided opening of the innominate vein may be closed just before separation from cardiopulmonary bypass. NB

STERNAL CLOSURE

Technique

Before sternal closure, chest tubes are placed in the mediastinal space and pericardial cavity for postoperative drainage.

Graft Injury

Chest tubes must be placed well away from arterial and vein grafts. Constant irritation and suctioning may perforate the grafts and cause brisk hemorrhage.

Myocardial Injury

The holes on the chest tubes must be oriented away from the myocardial surface to prevent suction injury and bleeding.

The sternum is reapproximated with six to eight stainless steel wires. Generally, the wires are passed around the sternum except for the manubrium where they are passed through the bone. Care must be taken to avoid injury to the internal thoracic vessels.

NB Alternating steel wires and cables in a figure-of-eight fashion can minimize the risk of sternal dehiscence (Fig. 1.9). However, it must be noted that when emergency opening of the chest in the intensive care setting is required, the removal of figure-of-eight wires and cables is more tedious and may delay resuscitative efforts. NB

In very ill patients who have difficulty being weaned from cardiopulmonary bypass, the heart and lungs become swollen and edematous. This is encountered more frequently in infants and young children. Closing the sternum in this subgroup of patients compresses the heart and compromises cardiac function. The chest is left open in such cases and covered with Ioban (3M Healthcare, St. Paul, MN), which allows visualization of the anterior mediastinum and rapid reentry, if needed. In children, a silastic patch is sewn to the skin edges. When hemodynamics become stable, the patient is returned to the operating room and the sternotomy is closed in the customary manner. Chest closure may be accomplished under sterile conditions in the intensive care unit.

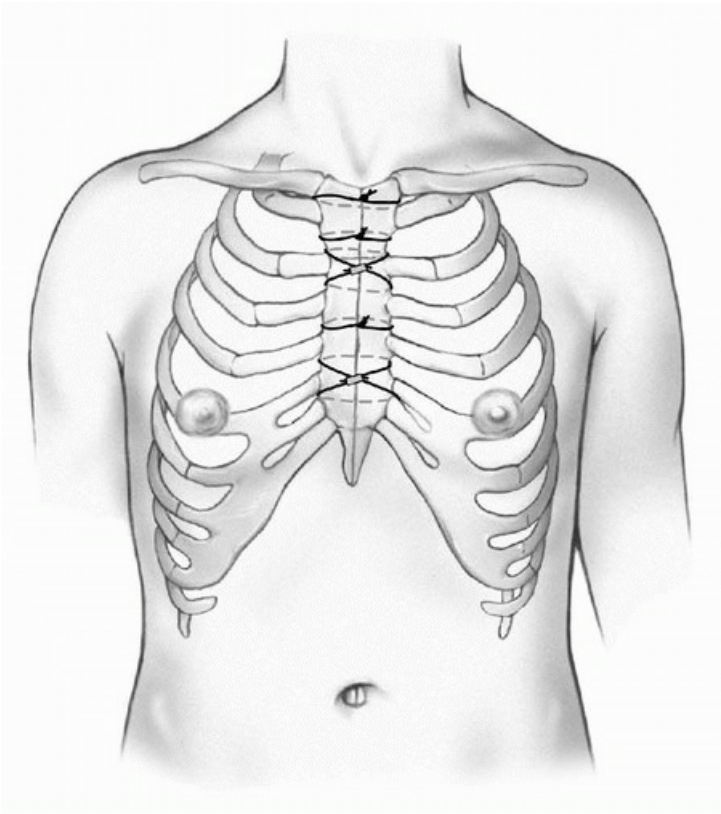

FIG. 1.9 Sternal closure with wires and cables.

NB The surgeon should not hesitate to use this very simple technique when indications are clear. This is a lifesaving measure, and the incidence of sternal infection is surprisingly low when rigorous sterile technique is maintained. NB

Loose Wires

The degree of postoperative pain is partly related to the stability of the sternal closure. Movement of the sternal halves causes pain and interferes with normal respiration, resulting in postoperative pulmonary complications. If the wires are loose, normal respiratory movements allow the wires to saw through the sternum (Fig. 1.10).

Robicsek Modification

When the sternum is osteoporotic and friable or the previous sternal closure has disrupted, Robicsek modification is successful in most patients. Running wire sutures are placed parasternally on both sides, followed by six to eight interrupted horizontal wire sutures that are placed outside the longitudinal parasternal wires and tightened in the usual manner (Fig. 1.11).

Fracture of the Sternum

Approximation of fractured sternal edges is a difficult task. Wires are passed parasternally above and below the fracture site, with the costal cartilages intervening. They are twisted tightly in the parasternal area to stabilize the fracture. These wires are then once again twisted horizontally across the sternum to close it in the usual manner (Fig. 1.12).

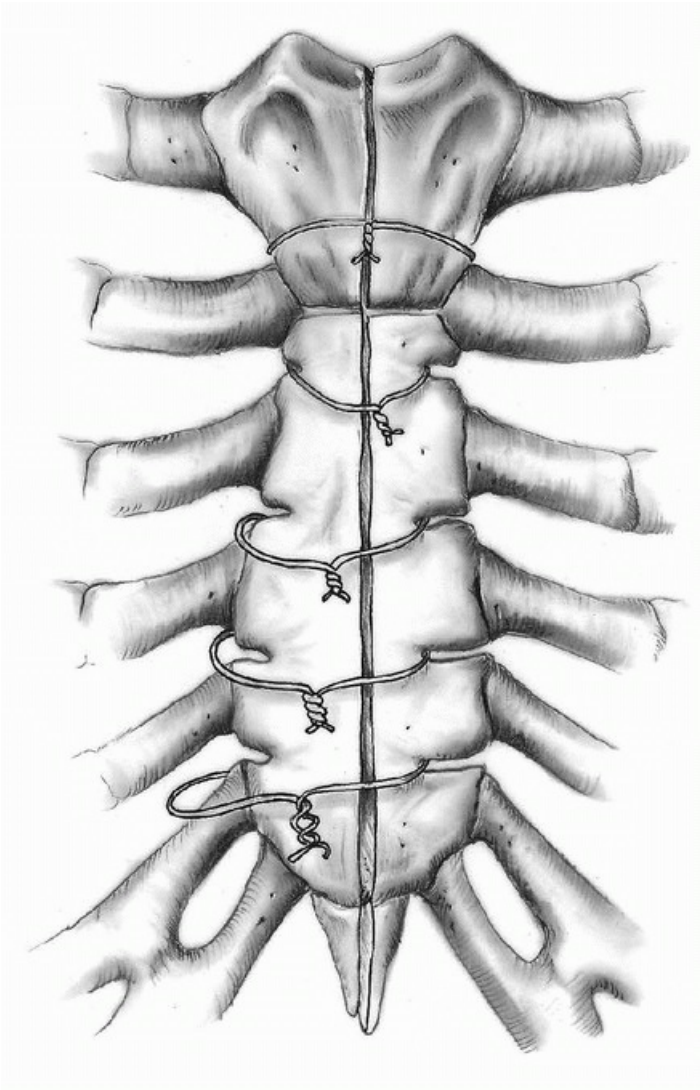

FIG. 1.10 Loose wires sawing through the sternum.

POSTOPERATIVE STERNAL WOUND INFECTION

Sternal wound infection occurs in 1% to 2% of patients undergoing cardiac surgery and carries a very high rate of morbidity and mortality.

General Considerations

General systemic factors such as malnutrition, cardiac cachexia, renal failure, chronic obstructive pulmonary disease, obesity, diabetes, and use of corticosteroids predispose the patient to postoperative sternal wound infection. Every attempt should be made to optimize the patient's state of health before surgery. This may require a period of nutritional supplementation or an aggressive therapeutic regimen to improve cardiac function. Pulmonary toilet and breathing exercises can be beneficial in patients with a history of chronic lung dysfunction. It is a good practice to recommend weight reduction in the very obese, but not to the extent that it produces negative nitrogen balance in the immediate preoperative period. Patients with insulin-dependent diabetes who undergo bilateral internal thoracic artery dissections are at increased risk of developing postoperative sternal wound complications. It is imperative that patients with diabetes have aggressive control of their blood glucose levels in the perioperative period. Long-term use of corticosteroids is associated with poor healing, and therefore, careful handling of tissue is required during surgery followed by meticulous closure of the wound.

Specific Technical Considerations

Specific technical factors that require consideration include internal thoracic artery dissection, excessive

postoperative bleeding, reexploration for bleeding, emergency opening of the wound in the intensive care unit, prolonged cardiopulmonary bypass, profound low cardiac output in the immediate postoperative period, and external cardiac massage. Careful control of bleeding points before heparinization ensures adequate hemostasis. After heparin has been administered, no clotting occurs; all capillary ooze must therefore be electrocoagulated and large vessels occluded with metal clips. In repeat surgeries when the resulting raw surfaces are great, the possibility of excessive bleeding must be contemplated. Only unhurried electrocautery dissection with step-by-step hemostasis can prevent excessive postoperative bleeding. There are times, however, when, despite all the preventive measures taken, postoperative bleeding may require exploration; occasionally, the chest may have to be opened in the intensive care unit to relieve acute tamponade. External cardiac massage may be a lifesaving measure, but it does give rise to sternal wound instability and wound complications and may be relatively ineffective in the early postoperative period. Low cardiac output and long perfusion time also have adverse effects on wound healing. Strict adherence to aseptic surgical technique and attention to detail during the surgery are important measures to prevent wound complications.

Wound drainage, with or without sternal instability, is the first sign of possible sternal wound infection. The patient may be septic and febrile, but often he or she is otherwise asymptomatic. After the diagnosis of infection is made, the patient is promptly taken to the operating room and is placed under general endotracheal anesthesia. Then, the incision is completely opened, and all necrotic tissue is debrided and excised. The sternal edges are trimmed to ensure viable bone. After a specimen is obtained for culture and testing for antibiotic sensitivity, the wound is irrigated with a dilute solution of 0.5% to 1% povidone-iodine (Betadine) or saline solution. If the patient is not septic and the wound appears to be clean, the sternum is closed in the usual manner. Robicsek modification is utilized if the sternum is weakened by wires cutting through it or thinned out due to debridement. Two large chest tubes are left behind the sternum and are connected to a closed drainage system. The drainage tubes should be maintained on low suction for 7 to 10 days. Any pleural tubes are then removed, taking the usual precautions to prevent a pneumothorax.

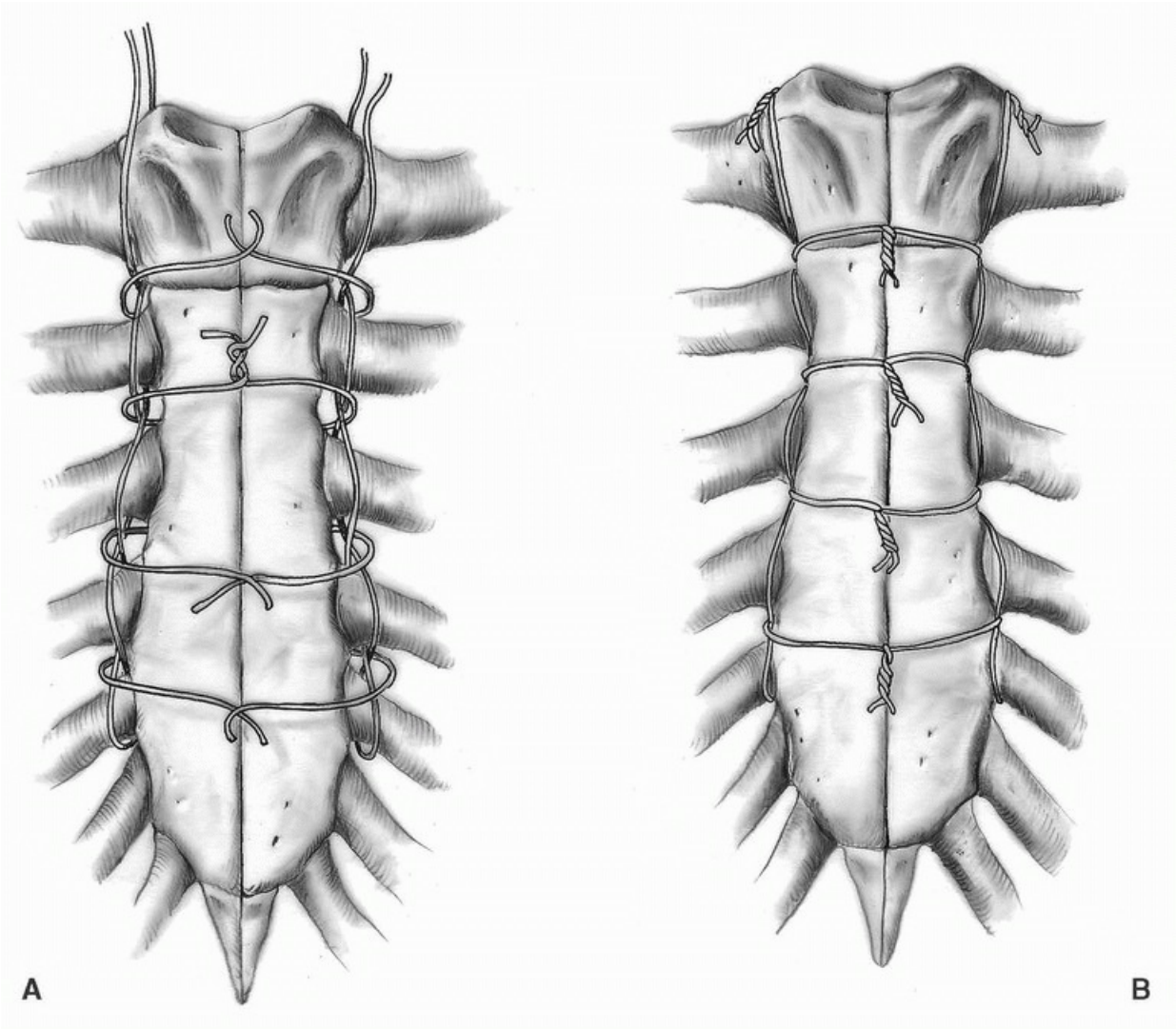

FIG. 1.11 Sternal closure with Robicsek modification.

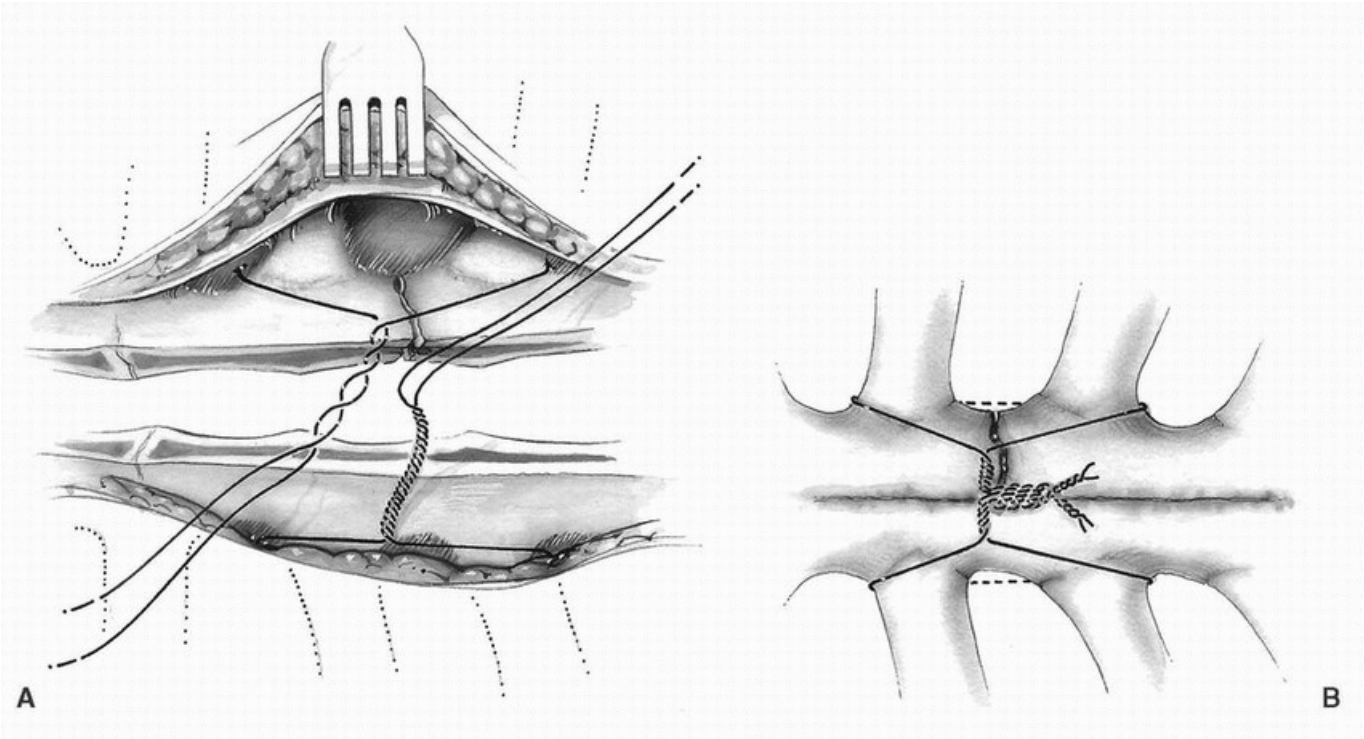

FIG. 1.12 Approximating segments of a fractured sternum.

Ischemic Necrosis

Surgeries are now being performed on a much older group of patients, many of whom have multisystem disease. Therefore, surgeons are encountering ischemic wound complications more frequently. In these cases, there is no definite evidence of infection, but necrotic bone and cartilage are present, which require careful debridement.

Placement of Tubes

Tubes should never be in direct contact with the aorta, vein grafts, or thoracic pedicle because they may cause local irritation, erosion, and serious hemorrhage (Fig. 1.13). The holes in the tubes should be oriented so that they are not in contact with the heart or the grafts to avoid suction injury and bleeding. The tubes should be placed on the thymic tissues superiorly or laterally in the gutter between pericardiopleural tissues and the undersurface of the sternum.

If the infection is massive or there is extensive necrosis, radical debridement is performed. To minimize the risk of reinfection, wide excision of the infected sternum and cartilage is critical. Extensive irrigation of the wound with a power irrigation system will reduce the number of organisms in the wound. When the wound appears to be clean and relatively free of overt infection, pectoralis muscle flaps or myocutaneous flaps are used for secondary closure (see subsequent text). If the quality of the subcutaneous tissues is questionable, the superficial wound should be packed open and delayed closure performed after a few days. In either case, systemic antibiotics should be continued for at least 7 days and for as long as 6 weeks in some patients.

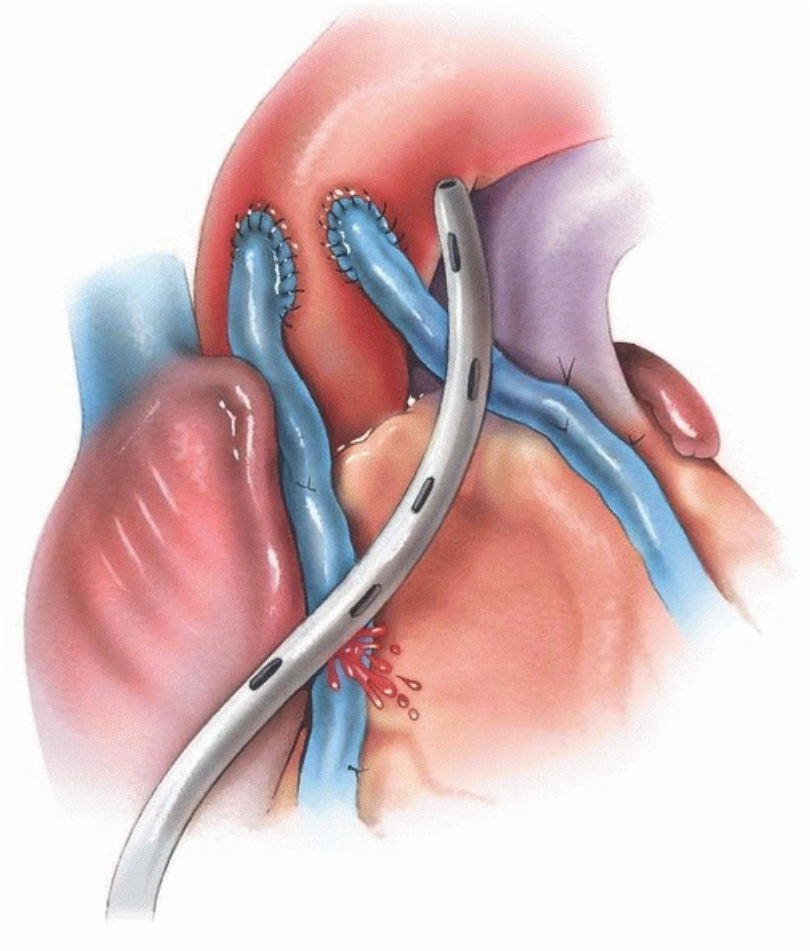

FIG. 1.13 Improper placement of a drainage tube.

Vacuum-Assisted Closure System

A very useful device for delayed closure of sternal or lower mediastinal wounds is the vacuum-assisted closure

system (VAC therapy, KCl, San Antonio, TX). It continuously removes fluid and promotes contraction of wound edges, thereby facilitating secondary closure. An advantage of this system is that dressing changes need to occur only once every 2 to 3 days.

Necrotic Cartilage

Costal cartilages that are necrotic and contaminated must be resected because their retention almost certainly leads to chronic draining sinus tracts.

Pectoralis Muscle Flap

Technique

Through the existing wound, the superficial surface of the pectoralis major muscle is exposed by elevating the overlying skin and subcutaneous tissue proceeding from the midline laterally. Dissection of the muscle off the chest wall is accomplished laterally toward the midline until the parasternal perforator arteries are encountered, usually 2 to 3 cm from the sternal border. The inferior free border of the muscle is identified, and blunt dissection is used to develop the plane deep to the pectoralis major and superficial to the pectoralis minor. A small incision is then made over the muscular insertion, being careful to preserve the cephalic vein for possible future pacemaker insertion. The humeral attachment is then divided, and the flap is advanced medially into the midline wound. The thoracoacromial pedicle must be divided to allow adequate mobility for folding the muscle into the sternotomy wound. When both pectoralis muscles are used, they are sutured together in the midline under slight tension. Occasionally, where one flap is sufficient, the muscle is sutured to the opposite sternal periosteum. The skin flaps are then advanced and closed primarily.

Choice of Muscle Flaps

Choice of muscle flaps should be thoroughly analyzed before beginning any procedure. The workhorse of mediastinal reconstruction is the pectoralis major muscle. The maximal bulk of muscle can be obtained using turnover pectoralis flaps based on parasternal perforating arteries from the internal thoracic artery. In most wounds of moderate to large size, bilateral flaps are necessary to fill the midline dead space. Occasionally, in narrower defects, a unilateral flap is sufficient.

Absence of the Internal Thoracic Artery

The internal thoracic artery is often used as a bypass conduit. In these cases, the parasternal perforator arteries have already been sacrificed, and the pectoralis flap should be based on the thoracoacromial pedicle.

Wound Coverage of the Lower Mediastinum

Regardless of the pectoralis flap technique, the inferior portion of the wound is most vulnerable. Turnover flaps are not sufficient to cover the lower one-fourth to one-third of the mediastinal structures. The VAC system is effective in promoting contraction of the wound edges. Introducing omentum into the chest wound has also been used to address such problems. Bringing omentum into the mediastinum necessitates entry into the peritoneum. This technique increases the morbidity of the surgery and carries the risk of spreading infection into the abdomen.

Superior Rectus Flap

An additional and effective technique is covering the lower mediastinal wound with the superior rectus abdominis muscle as a flap.

Technique

The sternotomy incision is extended inferiorly to the umbilicus. The chosen superior rectus abdominis muscle is exposed by elevating skin and subcutaneous tissue to the lateral edge of the muscle down to the level of the umbilicus, where the muscle is divided transversely. During transection of the muscle, the superior epigastric vessels are suture ligated to prevent a donor site hematoma. The muscle is then lifted off the posterior rectus sheath up to the costal margin.

Absence of the Internal Thoracic Artery

The superior epigastric artery is the continuation of the internal thoracic artery. It is important to know that the internal thoracic artery is intact and patent before mobilizing the superior rectus abdominis muscle. The arteries may have been used as a conduit for myocardial revascularization or been damaged by repeat sternal closure. A selective angiogram is always indicated.

Damage to the Epigastric Arteries

Care is taken not to damage the superior epigastric pedicle that emerges from beneath the costal margin to enter the muscle.

The flap may then be folded superiorly to fill the inferior third of the mediastinum. The rectus is sutured to the pectoralis flaps and the sternal border to maintain its position, and the anterior rectus sheath is repaired with nonabsorbable sutures.

Hematoma and Seroma

The most common complication is hematoma or seroma at the donor muscle site, whether pectoralis or rectus abdominis.

Myocutaneous Flap

The pectoralis major muscle is sometimes used as a myocutaneous flap to cover the infected sternal wound.

Technique

The sternal wound is debrided and irrigated with saline and povidone-iodine solution, as described previously. Bilateral musculocutaneous flaps of the pectoralis major muscle are dissected free off the chest wall to the level of the clavicles above, anterior axillary line laterally, and posterior rectus sheath inferiorly. This is accomplished with an electrocautery and blunt dissection. Perforating arteries are sacrificed.

The myocutaneous flaps are now advanced medially and approximated to each other in the midline over two to three closed-system drainage tubes with absorbable sutures. The skin is then closed with interrupted Prolene or in two layers with absorbable sutures.

THORACOTOMY

Posterolateral thoracotomy provides excellent exposure for many closed cardiac procedures, such as repair of coarctation of the aorta, shunting procedures, resection of aneurysms of the thoracic aorta, ductus arteriosus surgery, and closed mitral valve commissurotomy. Anterolateral thoracotomy may be all that is needed for some procedures. In practice, we elect to perform a lateral thoracotomy and extend it anteriorly or posteriorly as needed.

The patient is stabilized securely on the operating table in a lateral position. A small pillow or a roll is placed on both sides of the chest, and a small roll is placed under the axilla. Another pillow is placed between the knees. Often, the upper leg is extended on a pillow over the flexed lower limb. A wide strip of adhesive tape is stretched from one side of the operating table to the other across the patient's hip for additional stability.

Sciatic Nerve Injury

The tape should be carefully placed so that it does not slip and compress the sciatic nerve.

A skin incision is made approximately one to two fingerbreadths below the level of the nipple, beginning at the anterior axillary line. It is extended posteriorly below the tip of the scapula, then superiorly between the scapula and the vertebral column. After the subcutaneous tissues are divided with electrocautery, the latissimus dorsi and serratus anterior muscles come into view. These muscles are divided, and the scapula is allowed to retract with the shoulder upward, thereby providing exposure of the intercostal muscles. Depending on the posterior extension of the incision, the rhomboid and trapezius muscles may need to be divided.

Bleeding from Muscular Branches

Latissimus dorsi and serratus anterior muscles are quite vascular, particularly in patients with long-standing coarctation of the aorta, and therefore, their division may result in substantial blood loss. Therefore, it is essential to

identify each blood vessel and ligate it securely. Although cautery coagulation may suffice in many situations, larger vessels should be controlled with suture ligatures.

Muscle Sparing

Often, it may be possible to retract the serratus anterior muscle adequately to provide sufficient exposure for thoracotomy. This is particularly indicated in infants and children.

The desired interspace is selected by counting the ribs downward, bearing in mind that the uppermost rib that can be felt is the second rib, not the first. Excellent exposure for patent ductus arteriosus and coarctation of the aorta is provided through the fourth interspace. The intercostal muscle is incised using electrocautery until the parietal pleura comes into view. This, in turn, is opened, taking care not to injure the underlying lung tissue. The intercostal incision is then completed under direct vision.

Injury to the Lung

The anesthetist should temporarily deflate the lungs to protect the lung parenchyma during entry into the pleural cavity.

Injury to the Intercostal Vessels

The neurovascular bundle is protected by the ribs. The dissection must hug the upper border of the rib to avoid injury to the intercostal artery.

The rib retractor is spread gradually and incrementally to avoid rib fracture. If additional exposure is needed, either the lower or upper rib is resected and removed. Dividing and removing a segment of the rib posteriorly near its angle is equally effective.

Postoperative pain owing to rib fracture could be markedly decreased if the affected segment is divided and removed to prevent the fractured bone ends from moving against each other.

One or two chest tubes should be placed in the pleural space and brought out anteriorly. The ribs are approximated with four or five interrupted heavy sutures. The serratus anterior and latissimus dorsi muscles anteriorly and the rhomboid and trapezius muscles posteriorly are accurately and meticulously approximated with either interrupted or continuous sutures. The subcutaneous layer and the skin are then closed.

Needle Injury to the Intercostal Vessels

Care must be exercised when placing the pericostal sutures to avoid injuring the intercostal vessels.

NB Intercostal nerve block by injection of a long-acting local anesthetic agent near the intercostal nerves in the most posterior part of the incision two to three interspaces above and below the level of the incision is most effective in reducing postoperative pain. NB

ALTERNATIVE SURGICAL APPROACHES

To allow for earlier return of the patient to normal physical activities, achieve a better cosmetic result, and decrease the postoperative pain, many surgeons are utilizing alternative approaches to the heart. In addition to smaller incisions, minimally invasive approaches are being introduced to avoid sternotomy altogether and perform cardiac surgery without cardiopulmonary bypass. The least invasive of these procedures involves cannulation of the femoral artery and vein to provide cardiopulmonary support for performing valve surgeries by endoscopic techniques.

Two of these techniques involve a full sternotomy through more cosmetically acceptable skin incisions. Two minimally invasive approaches include lower or upper ministernotomy and submammary right thoracotomy.

NB Defibrillation

Because access within the pericardial space is limited, all patients undergoing cardiac procedures through a minimally invasive approach should have external defibrillator pads appropriately placed depending on the incision. Alternatively, sterile pediatric internal defibrillator paddles must be available on the operating table. NB

Full Sternotomy through Submammary Incision

A bilateral submammary skin incision results in a cosmetically acceptable scar and is used in girls and young women undergoing more complex cardiac procedures requiring a full sternotomy.

Technique

Skin incisions are made 0.5 cm below and parallel to the lowest contour of both breasts. The incisions are joined in the midline at the level of the junction of the sternum with the xiphoid process (Fig. 1.14).

Lower Limits of Breast Tissue

The precise limits of breast tissue in preadolescent girls may not be evident. It is important not to make the incision too high as this will result in a scar across the breasts. A transverse incision at the level of the xiphoid process with a slight superior deviation in the midline is a safe option.

The breasts and skin flaps are dissected off the pectoral muscles with a cautery blade. The skin flaps are then retracted with one or two heavy sutures. Superiorly, it is useful to tie the sutures to a Kerlix gauze roll, which is passed over the anesthesiologist's crossbar and secured to an appropriate weight (usually 5 to 10 lb).

Injury to Skin

A gauze or lap pad placed behind the heavy sutures protects the skin edges from pressure injury.

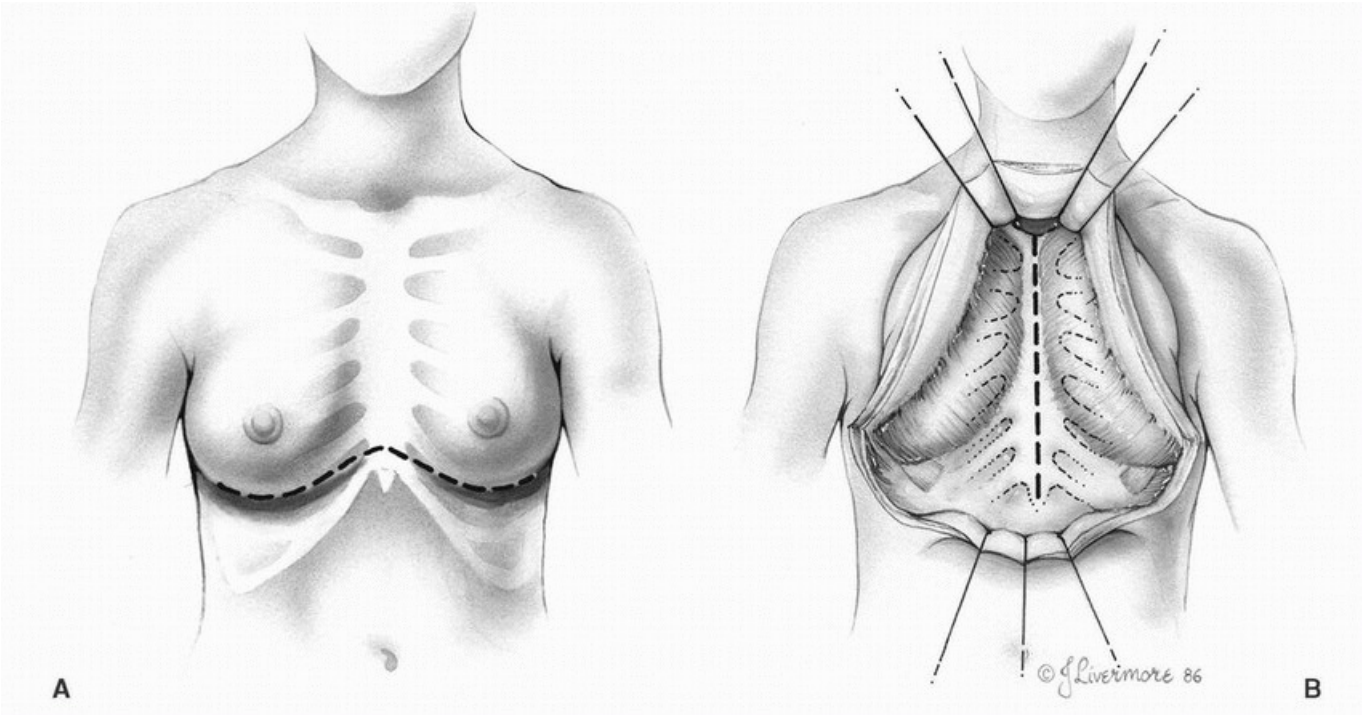

FIG. 1.14 Brom submammary approach.

The sternal opening and closure are performed in the usual manner. The skin flaps are allowed to fall naturally on the pectoral muscles. This position is secured with a few absorbable sutures. Two soft flat drainage catheters are placed behind the skin flaps and brought out through stab wounds at the lateral extremes of the incision. They are connected to a closed suction system.

NB Care must be taken to maintain the normal position of the breasts and alignment of the nipples to ensure satisfactory cosmetic results. NB

NB A single mediastinal chest tube is brought out through a small curvilinear incision just above the umbilicus to avoid an additional scar. NB

Full Sternotomy through a Limited Midline Incision

Full sternotomy allows safe access to the heart and permits performance of most of the cardiac procedures. It has been the approach of choice since the birth of cardiac surgery. Therefore, performing a full median sternotomy through a limited skin incision is most appealing.

Technique

The midline skin incision starts at the level of sternomanubrial junction and extends down toward the xiphoid process for approximately 8 to 12 cm depending on the procedure to be performed and the patient's body habitus (Fig. 1.15). Most mitral valve procedures can be accomplished through an 8 to 10 cm opening, but for aortic valve surgery and coronary bypass, grafting up to 15 cm may be required. The subcutaneous tissues are dissected free from the anterior surface of the entire length of the sternum with electrocautery. Often, it may be necessary to extend the dissection for 1 to 2 cm laterally onto the pectoralis muscle on both sides as well as superiorly into the suprasternal notch. It

may be possible to place a standard pneumatic sternal saw into the suprasternal notch and divide the sternum from above downward. At times, it may be necessary to use a pediatric or oscillating saw.

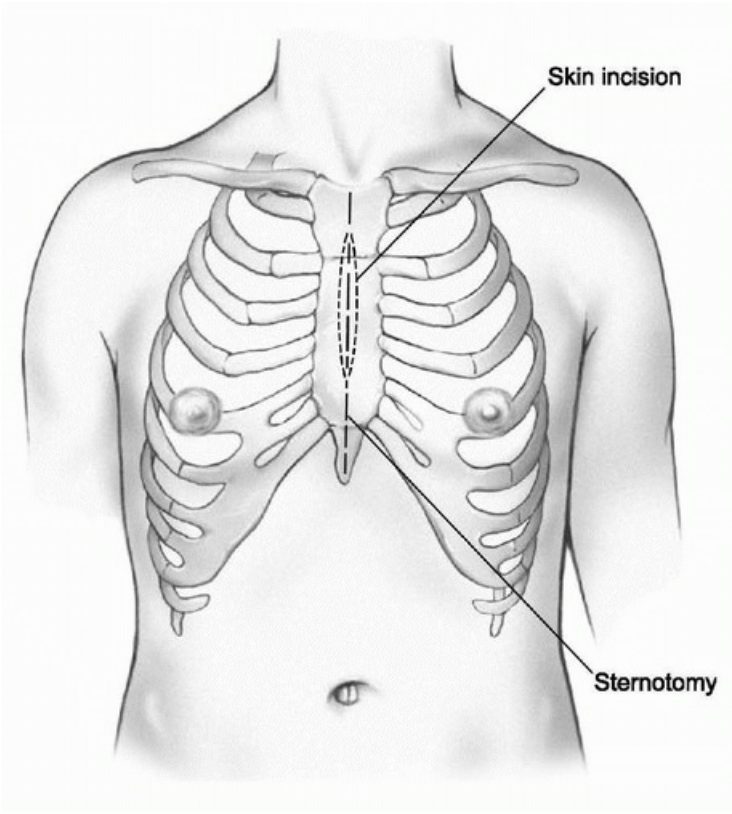

FIG. 1.15 Full sternotomy with limited skin incision.

Injury to the Skin

Both ends of the incision must be carefully retracted and protected from an oscillating saw when it is used to open the sternum. The lower end of the incision should be similarly retracted to prevent injury to the skin when the sternum is opened with the standard pneumatic saw from above.

A pediatric or small Finochietto sternal retractor is then used to spread the two halves of the sternum. The blades are opened very gently and just wide enough to provide adequate exposure. The pericardial edges are suspended from the skin drapes or sternal retractor to elevate the heart maximally into the operative field.

At the conclusion of the procedure, the sternum is closed with at least six wires. It is important to place two wires in the manubrium to assure maximum stability. The skin and subcutaneous tissues are closed in layers. If a significant potential space exists anterior to the sternum, a flat drain connected to closed suction is placed to prevent the accumulation of fluid.

NB This incision is cosmetically pleasing because it cannot be seen when patients wear most V-neck or open-collar tops. NB

NB The internal thoracic arteries and costal cartilages are not prone to injury with this approach. NB

Lower Ministernotomy

We have found the lower sternotomy through a limited skin incision to be an acceptable approach for atrial septal defects and some ventricular septal defects. It may also be used for off-pump coronary artery bypass graft procedures using the left internal thoracic artery.

Technique

The midline skin incision begins at the level of a line drawn between the two nipples and extends to the tip of the xiphoid process (Fig. 1.16). Dissection must be carried up to the level of the third interspace, and the pectoralis

muscle is dissected off the sternum to the right or left side. (For congenital heart defects, the right side is dissected, and for left internal thoracic artery harvest, the left side is used.) A saw is used to open the sternum in the midline to the level of the third interspace. Then, an angled bone cutter is used to divide the right or left half of the sternum into the third interspace (Fig. 1.17).

Injury to the Costal Cartilage

Every effort is made to ensure that the bone cutter divides the sternal half into the interspace between two ribs and not into the costal cartilage.

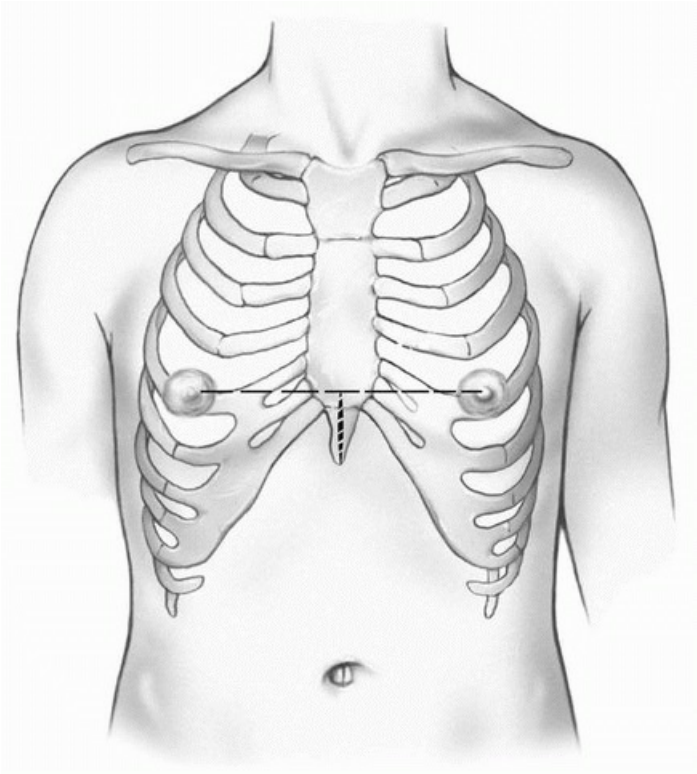

FIG. 1.16 Lower ministernotomy skin incision.

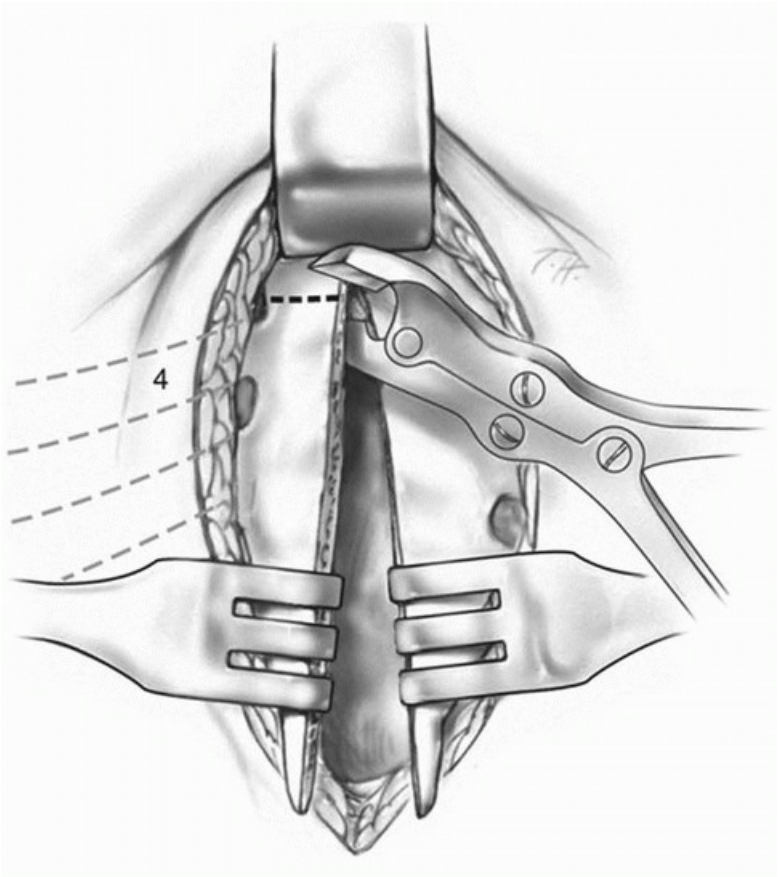

FIG. 1.17 After using a saw to divide the xiphoid and lower sternum, an angled bone cutter is used to divide the right half of the sternum into the third intercostal space.

Injury to the Skin Incision

The saw may injure the skin edges superiorly. This is avoided by pulling upward with a long narrow retractor on the upper extent of the skin incision to allow the saw to reach the level of the third interspace (Fig. 1.17).

A single- or double-blade thoracotomy retractor can then be placed between the two sternal halves, with the bar inferiorly and slowly opened. After opening the pericardium, traction sutures allow excellent exposure of the right atrium, inferior vena cava, lower superior vena cava, and proximal ascending aorta. Direct aortic cannulation can be achieved, but aortic cross-clamping may be difficult through this incision. Secundum and most sinus venosus atrial septal defects can be safely closed on cardiopulmonary bypass with induced ventricular fibrillation.

Exposure of the Superior Vena Cava

A tie placed around the tip of the right atrial appendage and pulled inferiorly allows adequate exposure of the superior vena cava.

Inability to Cannulate the Left Superior Vena Cava

If a left superior vena cava is present, this approach should not be used. Preoperative transthoracic echocardiography or an intraoperative transesophageal echocardiogram can usually make this diagnosis.

One advantage of the lower ministernotomy incision is that it can be easily extended to a full sternotomy, if necessary.

Lower Ministernotomy Closure

The upper and lower portions of the right side of the sternum are reapproximated with one stainless steel wire

placed vertically. The left and right halves of the lower sternum are encircled with three or four wires (Fig. 1.18). The vertical wire should not be tightened until all the wires are placed.

Malalignment of Right Side of the Sternum

Failure to approximate the upper and lower portions of the divided right hemisternum will result in a bony deformity at the level of the third interspace. Care must be taken to push the upper and lower portions into the same plane before tightening the vertical wire.

Distortion of the Superior Aspect of the Incision

Tight closure of the muscle layers superiorly will create a dimpling effect. The tissue should be loosely approximated cephalad to the skin opening.

Upper Ministernotomy

Some surgeons perform aortic procedures through an upper ministernotomy. This incision provides adequate exposure of the aorta and left ventricular outflow tract.

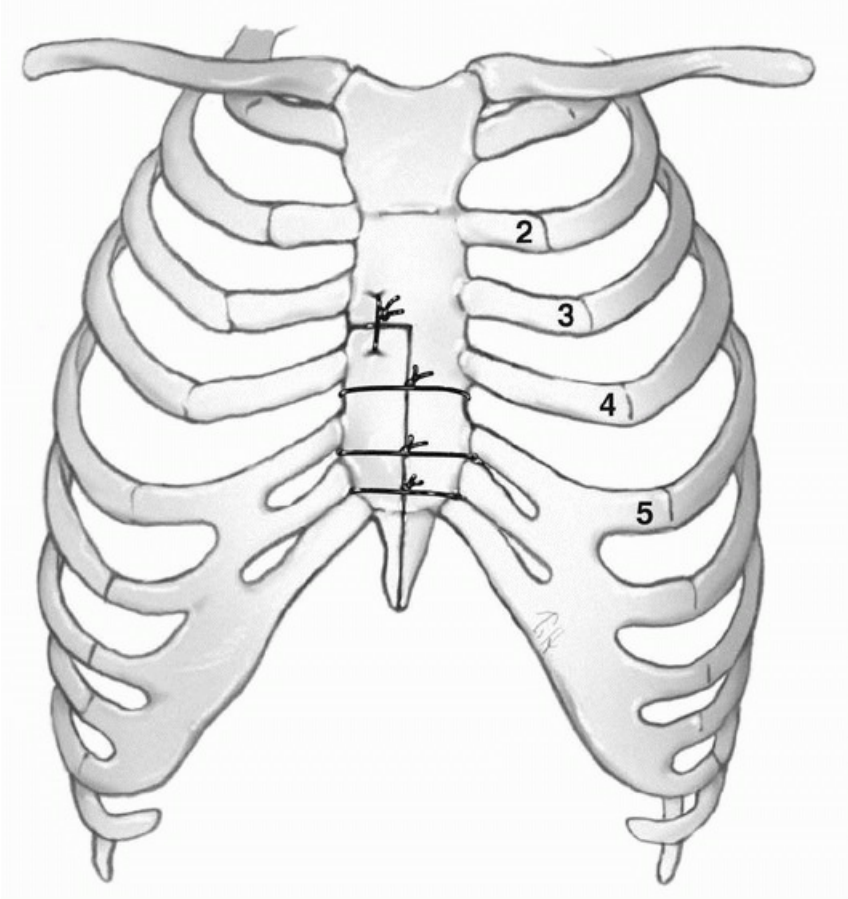

FIG. 1.18 Reapproximation of the lower sternotomy with one vertically placed wire and three horizontal wires.

Technique

A 6- to 8-cm midline skin incision is made starting approximately 2 to 3 cm below the suprasternal notch. Short flaps of subcutaneous tissue are developed both superiorly and inferiorly to expose the sternum. With a pneumatic or a small oscillating saw, the sternum is divided from the suprasternal notch down to the third or fourth interspace. An angled bone cutter is used to divide the sternum into the right, left, or both intercostal spaces. A Finochietto sternal retractor provides good exposure.

Injury to Internal Thoracic Artery

The retractor blades should be opened carefully to prevent damage to the internal thoracic vessels. Similarly, the bone cutter may injure these vessels.

Injury to Costal Cartilages

The bone cutter should divide the sternal half into the intercostal space and not into the costal cartilages.

Skin Injury

The upper and lower ends of the skin incision must be protected from saw and traction injuries.

Improving Exposure

Wide excision of the thymic and fatty tissues improves the exposure.

Use of Retrograde Cardioplegia

Insertion of the retrograde cannula is more easily accomplished before venous cannulation. The cannula is introduced into the right atrium through a purse-string suture below the right atrial appendage. Gentle traction on the right atrial appendage facilitates the cannula placement. It is advanced into the coronary sinus under transesophageal echocardiographic guidance.

Minimizing Air in Left Ventricle

The usual deairing techniques may not be feasible through this incision (see Chapter 4). Flooding the operative field with CO_2 through an intravenous tubing attached to the edge of the incision will displace air and decrease the possibility of air embolism.

At the completion of the procedure, a soft drain is placed in the mediastinum and brought out below the xiphoid process. Placement of this drain is best accomplished when the heart is empty on cardiopulmonary bypass. The sternum is closed with four wires, two of which are placed in the manubrium. The upper and lower portions of the right, left, or both sides of the sternum are reapproximated with a wire placed vertically. The subcutaneous tissues and skin are closed in layers.

Submammary Right Thoracotomy

This incision is cosmetically very appealing for young girls and women requiring atrial septal defect closure. It may be used for mitral valve surgeries, although access to the ascending aorta for cross-clamping may be difficult.

Technique

The skin incision is made in the submammary fold of the right breast in an adult or the anticipated future breast fold in a preadolescent girl (Fig. 1.19). This is carried down to the chest wall, and the pectoralis major and pectoralis minor insertions onto the ribs are dissected free up to the fourth interspace. The intercostal muscle is divided just on the upper edge of the 5th rib, and the pleural space is entered.

Two single-blade retractors are placed: one between the ribs and the other at a right angle to the first retractor to spread the subcutaneous tissue and muscle. A lung retractor is then used to hold the right lung laterally (Fig. 1.20).

After opening the pericardium, traction sutures can be placed to allow for exposure of the inferior vena cava, superior vena cava, and proximal ascending aorta. A tie around the tip of the right atrial appendage retracted inferiorly aids in cannulation of the superior vena cava and ascending aorta.

Inability to Cannulate the Left Superior Vena Cava

A left superior vena cava is not accessible from this approach.

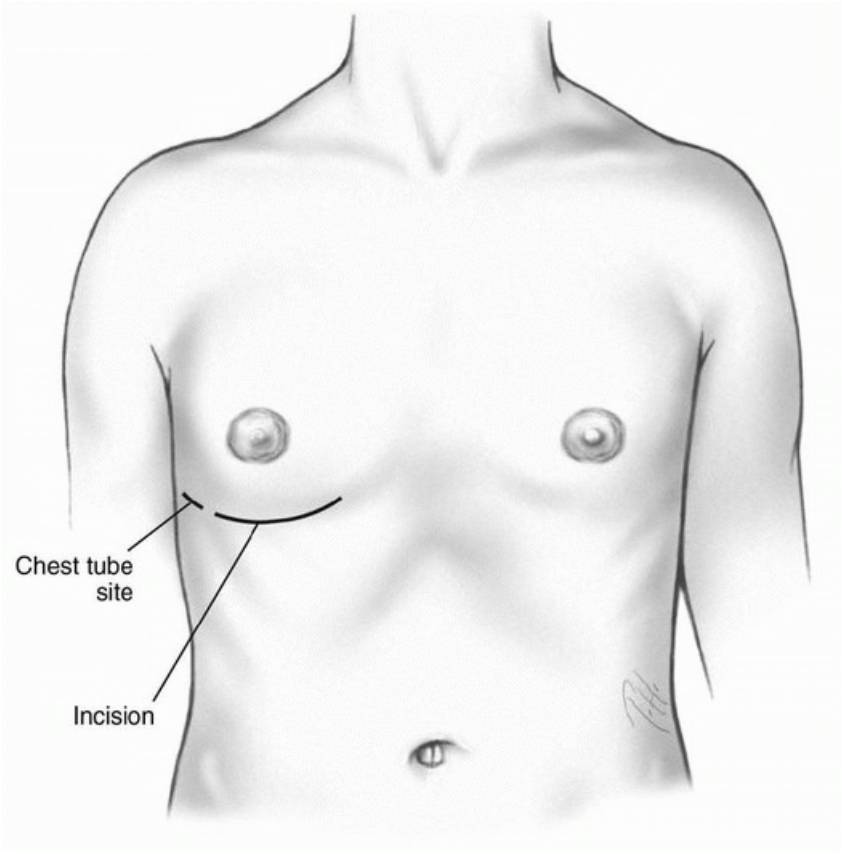

FIG. 1.19 Submammary right thoracotomy skin incision. Note the location of the chest tube.

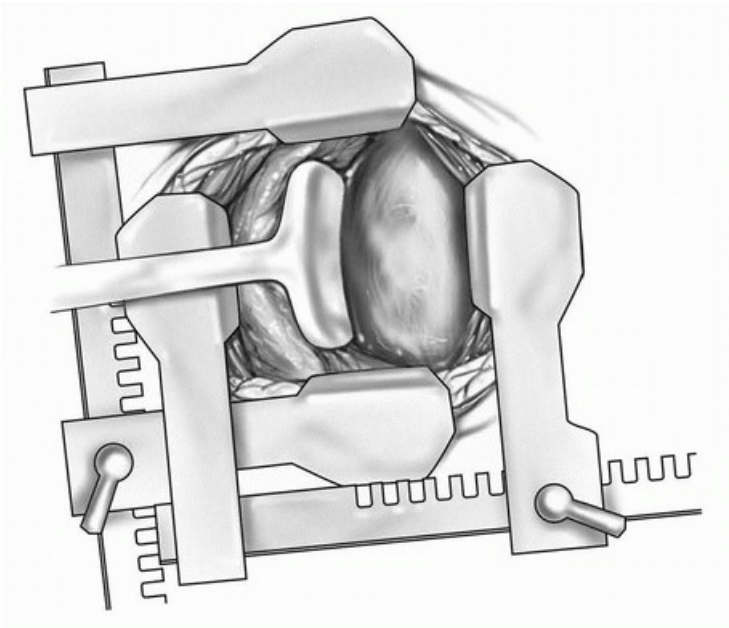

FIG. 1.20 The first single-blade retractor spreads the ribs, the second single-blade retractor retracts the muscle, and a T-shaped retractor holds the lung laterally.

Difficult Ascending Aortic Cannulation

The ascending aorta in older children and adults may be difficult to cannulate through this incision. The use of an arterial cannula with a tapered introducer may allow for safe and controlled aortic cannulation when aortic exposure is suboptimal. Femoral arterial cannulation through a small horizontal groin incision may often be

required.

Damage to the Right Internal Thoracic Artery

Injury to the right internal thoracic artery should be avoided by opening the intercostal muscle carefully toward the sternum.

Closure of Submammary Right Thoracotomy

After placing a chest tube through a small stab wound just lateral to the skin incision (Fig. 1.19), the ribs are reapproximated with heavy braided sutures. The muscle, subcutaneous layers, and skin are then closed in layers.

Correct Chest Tube Placement

The chest tube should be inserted through an incision just lateral to the skin opening. Placement of the chest tube lower than the submammary line creates an unnecessary scar that is not hidden by the usual two-piece bathing suit or tube top.

Intercostal nerve blocks with a long-acting local anesthetic in several interspaces can be administered before chest closure from within the pleural space. This decreases the need for parenteral pain medications in the postoperative period.

2
Preparation for Cardiopulmonary Bypass

EXPOSURE OF THE HEART

Technique

The remnant of the thymus gland is dissected free from the pericardium. The thymic vessels are all electrocoagulated to prevent the formation of a hematoma or troublesome oozing during the operation. The larger ones should be occluded with metal clips. The pleura is peeled away from the inferior pericardium with a dry sponge, thereby preventing inadvertent entry into the pleural cavities. The electrocautery blade can be used to incise the pericardium and at the same time coagulate the edges. This maneuver may trigger ventricular fibrillation if the cautery blade touches the heart. It is therefore preferable to incise the pericardium with a pair of scissors or a scalpel. The pericardium can then be opened in the usual inverted T fashion and suspended from skin edges or the retractor (Fig. 2.1).

The sternal retractor should be opened gradually without traumatizing the sternal edges. It can be positioned in such a manner that its cross-arm is in the upper part of the wound. This technique helps to prevent entanglement or overcrowding of various pump lines. The blades of the retractor should be placed as low as possible, and the sternum should be opened only to the extent that is essential for adequate exposure. This prevents possible fracture of the first rib and brachial plexus injury (see Fig. 1.2). Many surgeons prefer sternal retractors with three to four blades, which can swivel horizontally and thereby lessen the stress on the sternal edges.

Dissection Around the Aorta

The posterior aspect of the aorta is not always free, and therefore the cross-clamp may not include the entire wall of the aorta (Fig. 2.2). Often, it helps to mobilize the aorta to ensure its complete cross-clamping. In primary cardiac surgeries, the area between the pulmonary artery and aorta is dissected in a limited manner to allow a large curved or right-angled clamp to be passed behind the aorta. In redo surgeries, some sharp dissection behind the aorta must be carried out as well. When a clear passage is created, the clamp is used to pass an umbilical tape around the aorta. Traction on the tape allows the aorta to be lifted out of its bed (Fig. 2.3).

NB Adventitial tissue on arteries and veins is an integral component of the vascular walls. It should not be dissected free but kept intact whenever possible. NB

Incorporation of adequate adventitial tissue in closure of the aortotomy or various cannulation sites, including the superior vena cava and pulmonary artery, is a safe and effective technique. The adventitial component is a natural tissue that acts like a reinforcing pledget, adding strength to the closure.

Injury to the Aorta

During dissection and passing of the clamp behind the aorta, care must be taken to avoid injury to the posterior wall (Fig. 2.4). If such a complication occurs, it is best to control the bleeding digitally or by packing the area while preparations are made to initiate cardiopulmonary bypass (Fig. 2.5). With the patient on bypass and the aorta cross-clamped, the aorta is opened and the posterior wall is repaired under direct vision (Fig. 2.6).

Injury to the Right Pulmonary Artery

On rare occasions when the right pulmonary artery takes a more caudal course, it may be injured during dissection around the aorta. If such a problem arises, it is best to control the bleeding by packing the area and to correct the lesion when the heart is decompressed on full cardiopulmonary bypass. The right pulmonary artery

can also be injured during dissection of the superior vena cava, especially when passing a tape around this vessel (Fig. 2.7).

Dissection Around the Cavae

Dissection required to pass umbilical tapes around the venae cavae in preparation for total cardiopulmonary bypass may be tedious and occasionally may result in injury to the great veins. The parietal pericardium is divided on each side of the vena cava, and a plane is established that allows an appropriate curved clamp to be passed around the cava with ease. The umbilical tapes are then introduced around each vessel with a curved clamp.

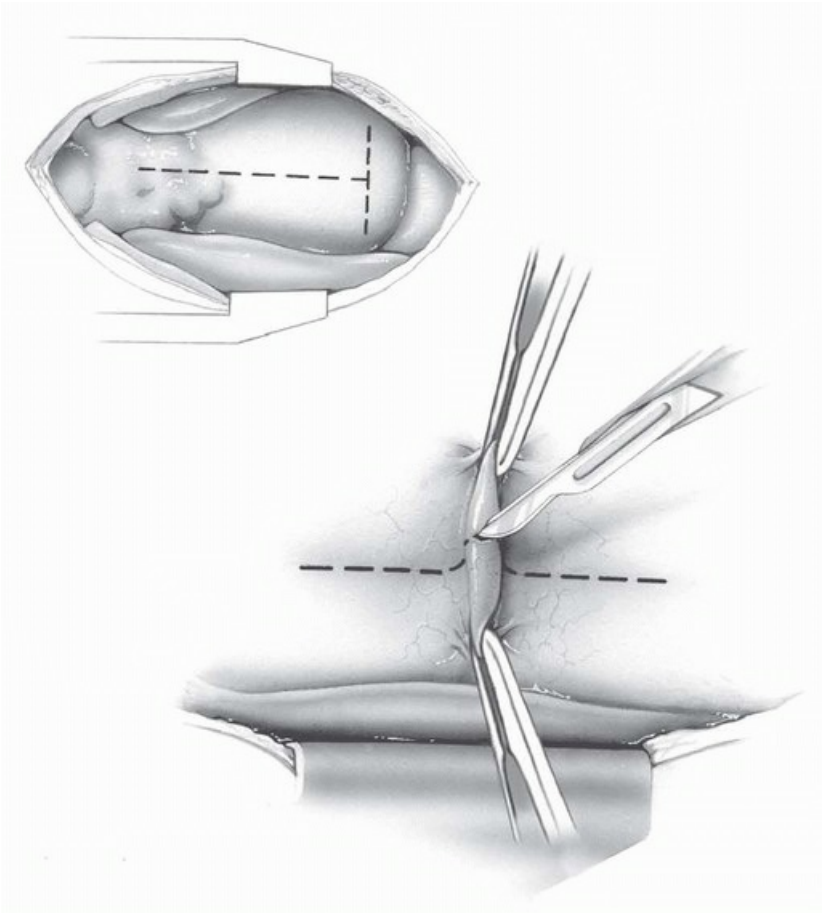

FIG. 2.1 Opening the pericardium.

Phrenic Nerve Injury

Dissection around the venae cavae can be cumbersome, particularly if extensive adhesions from previous surgery are present. The right phrenic nerve coursing along the lateral aspect of the cavae and the right atrium on the pleural aspect of the pericardium can easily be injured, either by sharp dissection or injudicious use of cautery. This results in paralysis of the right hemidiaphragm and complicates the ventilatory care of the patient in the postoperative period. The surgeon should therefore attempt to avoid the right phrenic nerve at all costs.

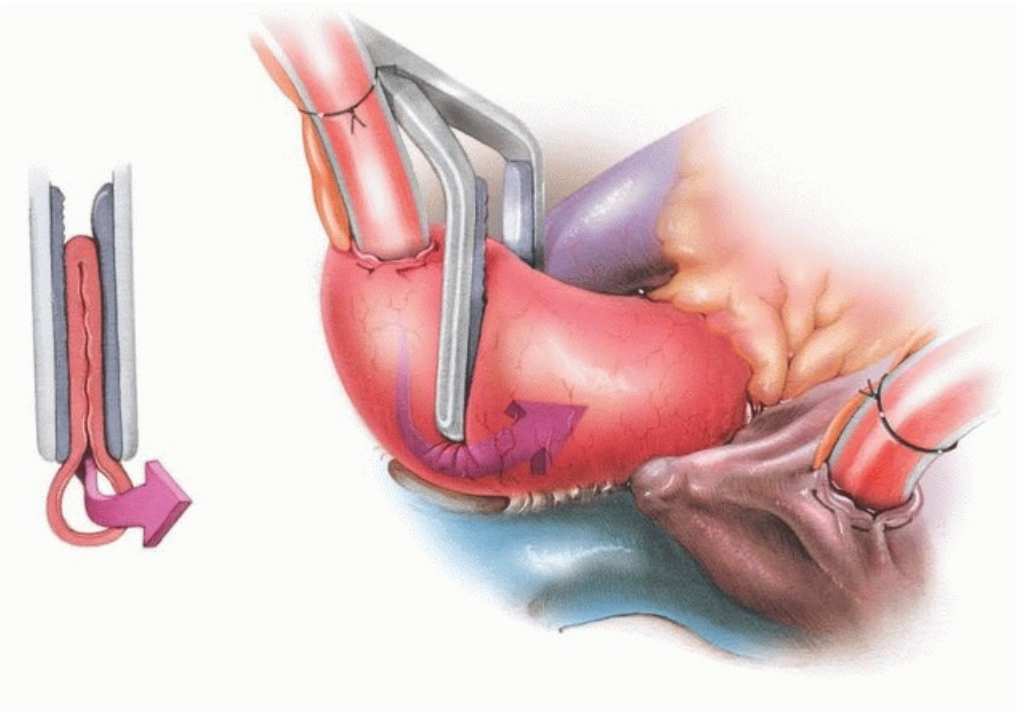

FIG. 2.2 Incomplete cross-clamping of the aorta.

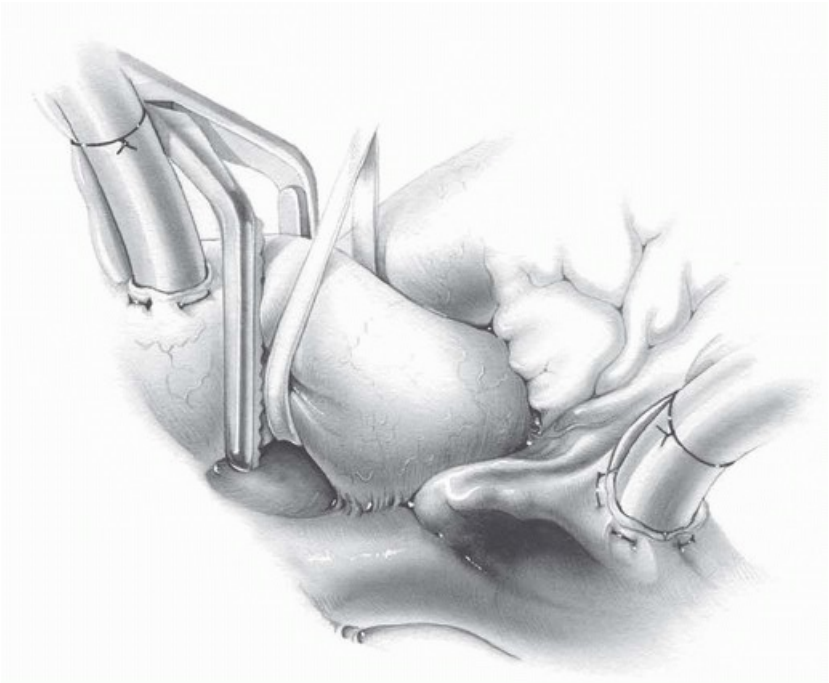

FIG. 2.3 Lifting the aorta from its bed.

Caval Injury

Caval injury is initially controlled digitally. Cardiopulmonary bypass is established, cannulating the aorta and either the inferior vena cava or right atrial appendage, and the problem is managed under direct vision. The site of the tear is brought into view by gently retracting the great vein with an atraumatic tissue forceps, at which time it can be sutured with fine Prolene. On rare occasions when the

torn caval wall is very friable, the suturing may incorporate an adjacent segment of the intact pericardial wall for buttressing and therefore hemostasis. Tension on the suture line is relieved by a curvilinear incision of the pericardium (Fig. 2.8). Alterantively, a patch of autologous or bovine pericardium can be used to repair the vena

caval injury. Repair should be done such that there is no hemodynamically significant narrowing of the cavae.

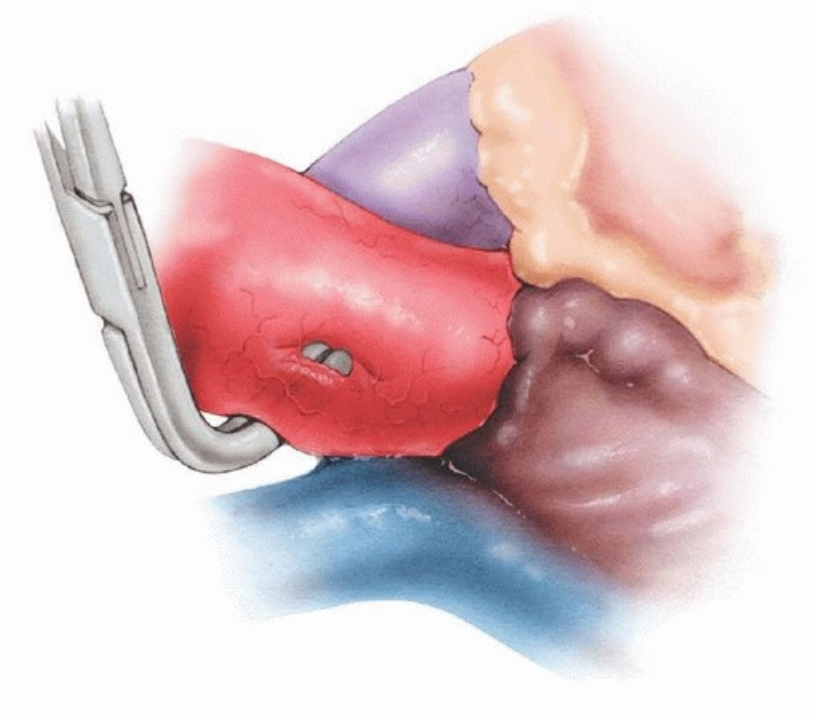

FIG. 2.4 Clamp injury to the aorta.

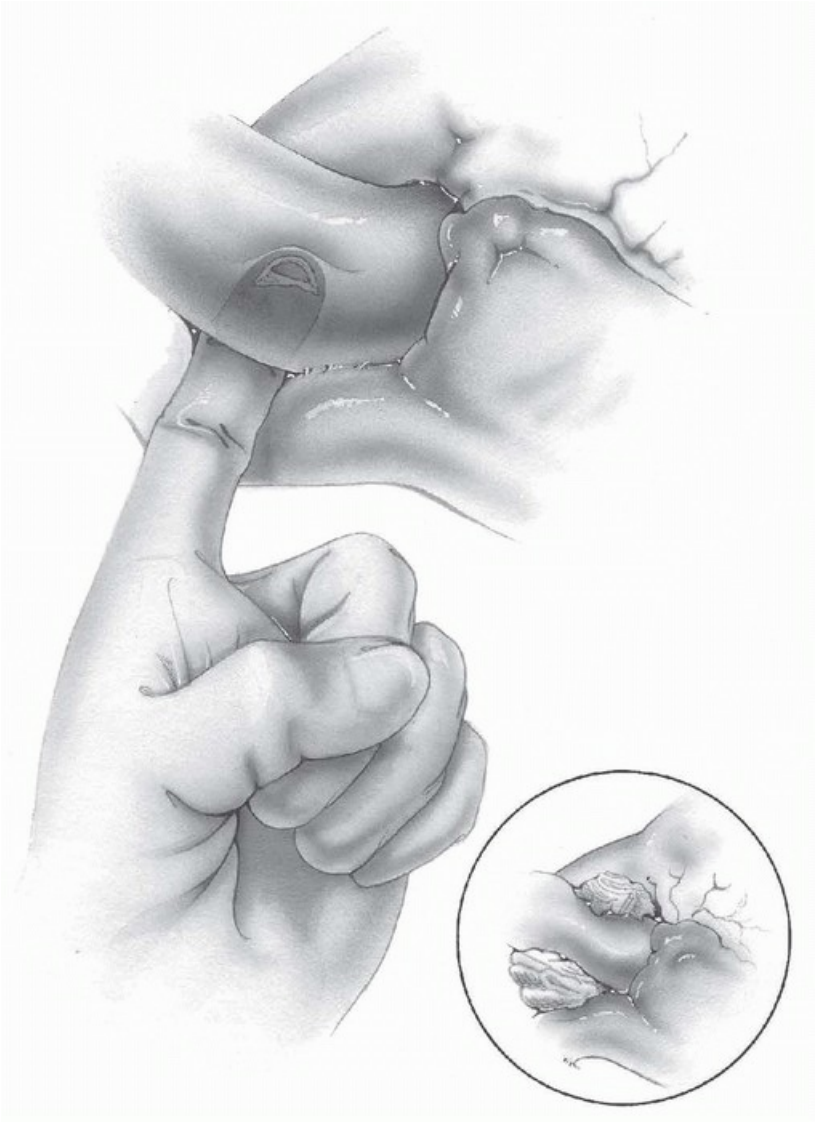

FIG. 2.5 Controlling bleeding after injury to the aorta.

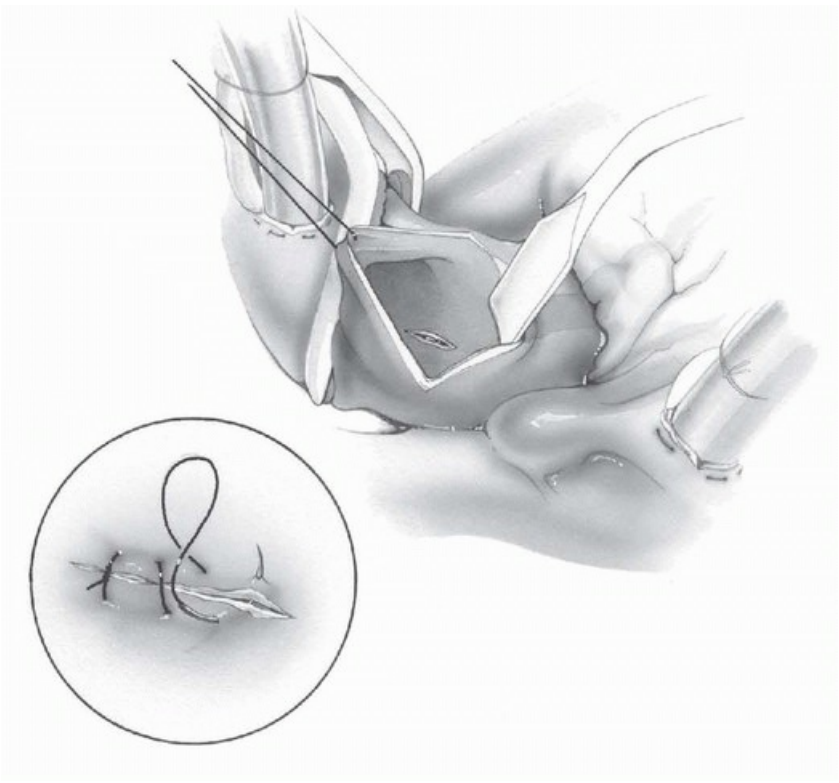

FIG. 2.6 Repair of the posterior wall of the aorta under direct vision.

ARTERIAL CANNULATION

Aortic Cannulation

Technique

Except in a few specific instances, the aorta is directly cannulated for arterial perfusion during cardiopulmonary bypass. Small bites of the adventitia and media as high up on the aorta as feasible are taken with 2-0 or 3-0 Prolene sutures on noncutting needles to form a single or double purse-string. Once the systemic systolic pressure is lowered below 90 mm Hg, a stab wound is made using a 15 blade to scratch the outer layers of the aorta before final entry. The tip of the aortic cannula is then introduced atraumatically into the opening (Fig. 2.9). The sutures can be buttressed with felt or pericardial pledgets to prevent bleeding from the needle holes. The ends of the purse-string sutures, which have passed through a long, narrow rubber or plastic tube, are secured. The tubing is then tied to the aortic cannula and, if desired, further secured to the edges of the wound (Fig. 2.10). The aortic cannula is allowed to fill retrogradely with blood. It is then connected to the arterial line, making sure that all air and foam have been removed from the circuit.

NB In patients undergoing reoperation with scarred aortic walls or pediatric patients, it may be useful to insert an

appropriately sized Hegar dilator through the stab wound before inserting the aortic cannula. NB

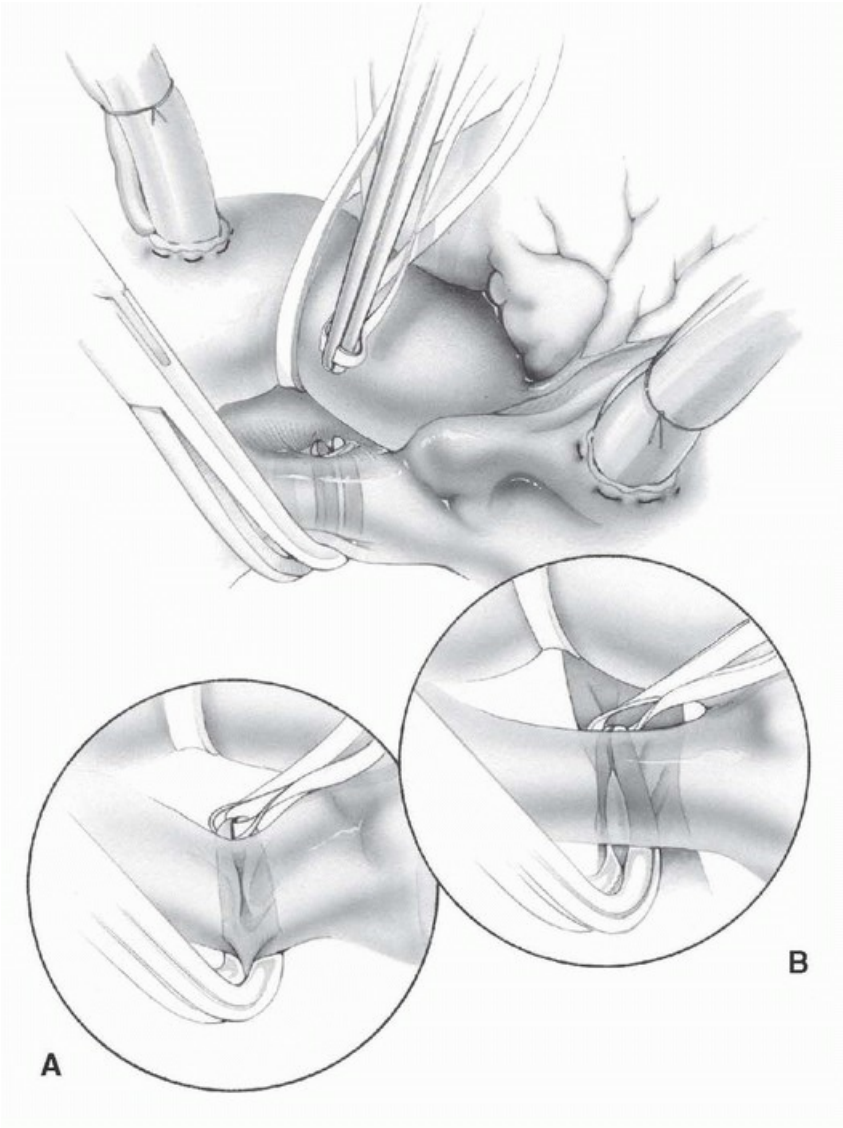

FIG. 2.7 Injury to the right pulmonary artery and superior vena cava. **A:** The clamp has caught the posterior wall of the superior vena cava. **B:** The clamp has caught the anterior wall of the right pulmonary artery.

Aortic Wall Atherosclerosis

Although this technique of aortic cannulation is a generally safe approach, serious vascular complications may nevertheless occur. Transesophageal echocardiography and epiaortic ultrasonographic scan of the ascending aorta are more sensitive for confirmation and localization of atheromatous changes. The aorta should also be routinely palpated for localized thickening and calcific plaques. The site for cannulation should be disease-free if possible. Usually, the anterior aspect of the aorta just proximal to the base of the innominate artery or the segment along the inner curvature of the aorta adjacent to the pulmonary artery is relatively free of calcification.

NB Epiaortic scanning should be performed before the placement of the purse-string sutures. The transducer is passed into a sterile plastic bag, with the tip coated with lubricating jelly to enhance image quality. The pericardial cavity is filled with warm saline and the aortic arch and ascending aorta are scanned. NB

Porcelain, Lead Pipe, or Eggshell Aorta

Porcelain, lead pipe, or eggshell aorta is the term used when the entire ascending aorta is calcified. Cannulation or clamping of this kind of aorta has catastrophic complications, namely, stroke and uncontrollable hemorrhage. In such cases, the femoral or axillary artery and right atrium are cannulated and the aorta is replaced or dealt

with under deep hypothermic circulatory arrest (see Management of Porcelain Aorta in Chapter 5).

Side-Biting Clamps

Partial occluding clamps should be avoided, especially when the aortic pressure is high, unless they are needed to control brisk hemorrhage or other complications. A clamp can crush the diseased wall and give rise to a tear of the intima, resulting in dissection of the aortic wall or disruption with massive bleeding.

Thin Aortic Wall

Whenever the aortic wall is thin or friable, the purse-string sutures are reinforced with Teflon or pericardial pledgets on each side of the cannula to prevent any injury to the aortic wall or bleeding from the needle sites (Fig. 2.10).

Large Aortic Cannula

Aggressive introduction of too large an aortic cannula through a small aortic opening can tear the aortic wall, dislodge calcific plaques, and cause separation of the intima and dissection around the cannulation site (Fig. 2.11). An expanding adventitial hematoma may be the first sign of traumatic aortic dissection. The cannula must be removed immediately and the cannulation site excluded carefully with a side-biting clamp (which in itself may further the dissection) to prevent progression of the dissection. On these occasions, retrograde perfusion through the femoral artery should be established promptly and the aortic injury dealt with under controlled conditions.

Small Aortic Cannula

An excessively small cannula may create a significant gradient in the perfusion pressure. Too great a length of cannula in the aorta may interfere with perfusion of the arch vessels, especially if the tip enters one of the brachiocephalic vessels. The ideal aortic cannula should have a relatively wide but short tip. Although most commercially available cannulas are manufactured with these specifications in mind, the size of the aorta varies in different individuals; therefore, the surgeon must select the appropriate length and width of the cannula judiciously.

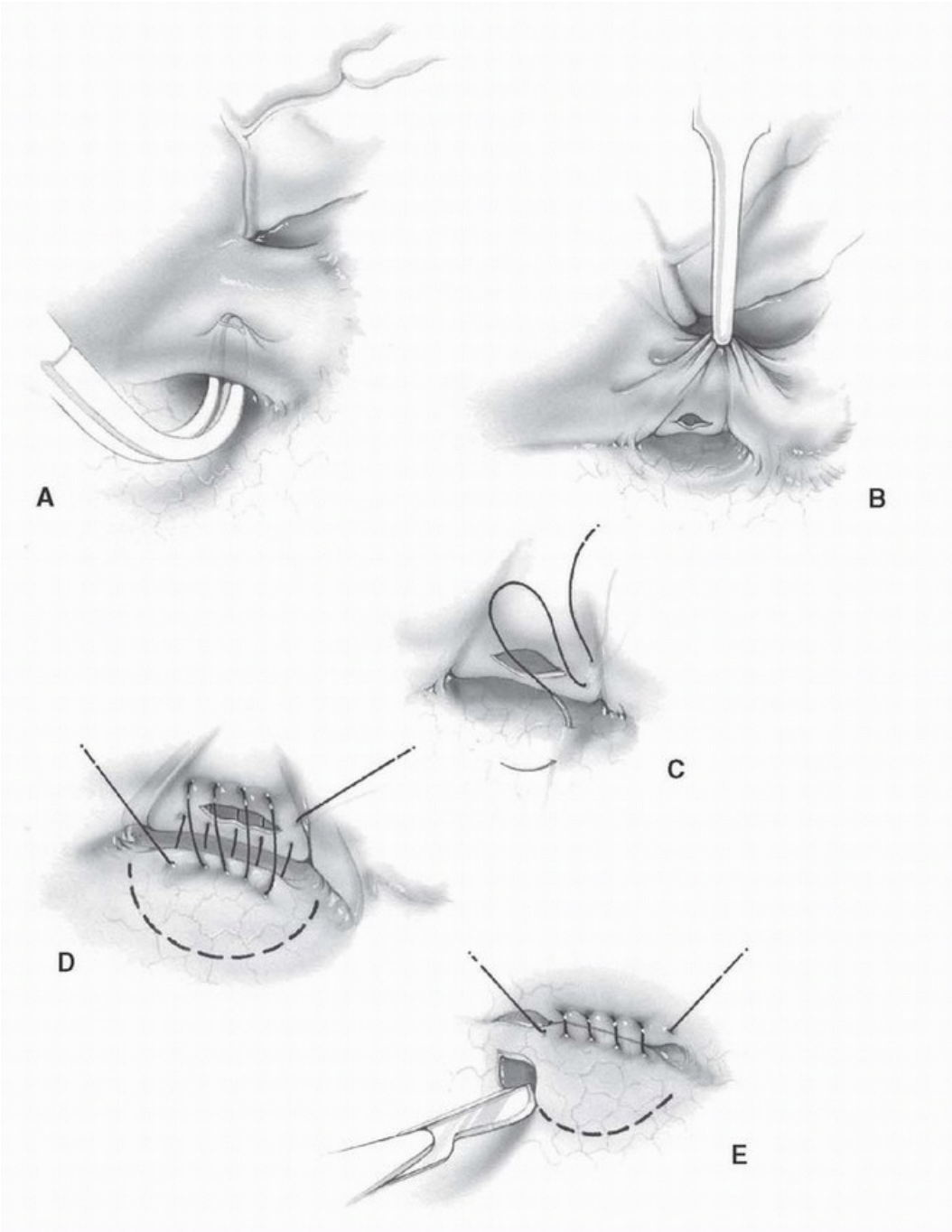

FIG. 2.8 A-E: Technique for repair of vena caval injury.

NB Small-Diameter Aorta

In patients with a relatively small-diameter aorta, the regular cannula may be space occupying, interfering with satisfactory perfusion. Plastic right-angled cannulas have good flow characteristics and will not hit the back wall of the aorta. NB

Systemic Hypertension

Whenever the systemic pressure is high, aortic decannulation may become hazardous and result in troublesome bleeding. The systemic pressure can be lowered to a satisfactory level by temporarily removing some volume through the venous line. The arterial cannula is then removed and its aortic entry site securely sutured. The arterial line is then connected to the venous cannula, and blood is reinfused as needed.

A less effective but useful technique is transient lowering of the blood pressure by digital compression of the main pulmonary artery for decannulation purposes. This technique can also be helpful when cannulating the aorta.

NB Repairing Aortic Injury

If the venous lines have already been removed, the cavae can be temporarily clamped, causing the systemic pressure to drop significantly. The aortic cannula is removed, and the now soft, pliable aorta is repaired. The caval clamps are then removed to allow drainage of the venous return into the right atrium. However, it is preferable to recannulate the right atrium and manipulate the blood pressure by adding or removing volume, thereby allowing for safe and controlled aortic repair. NB

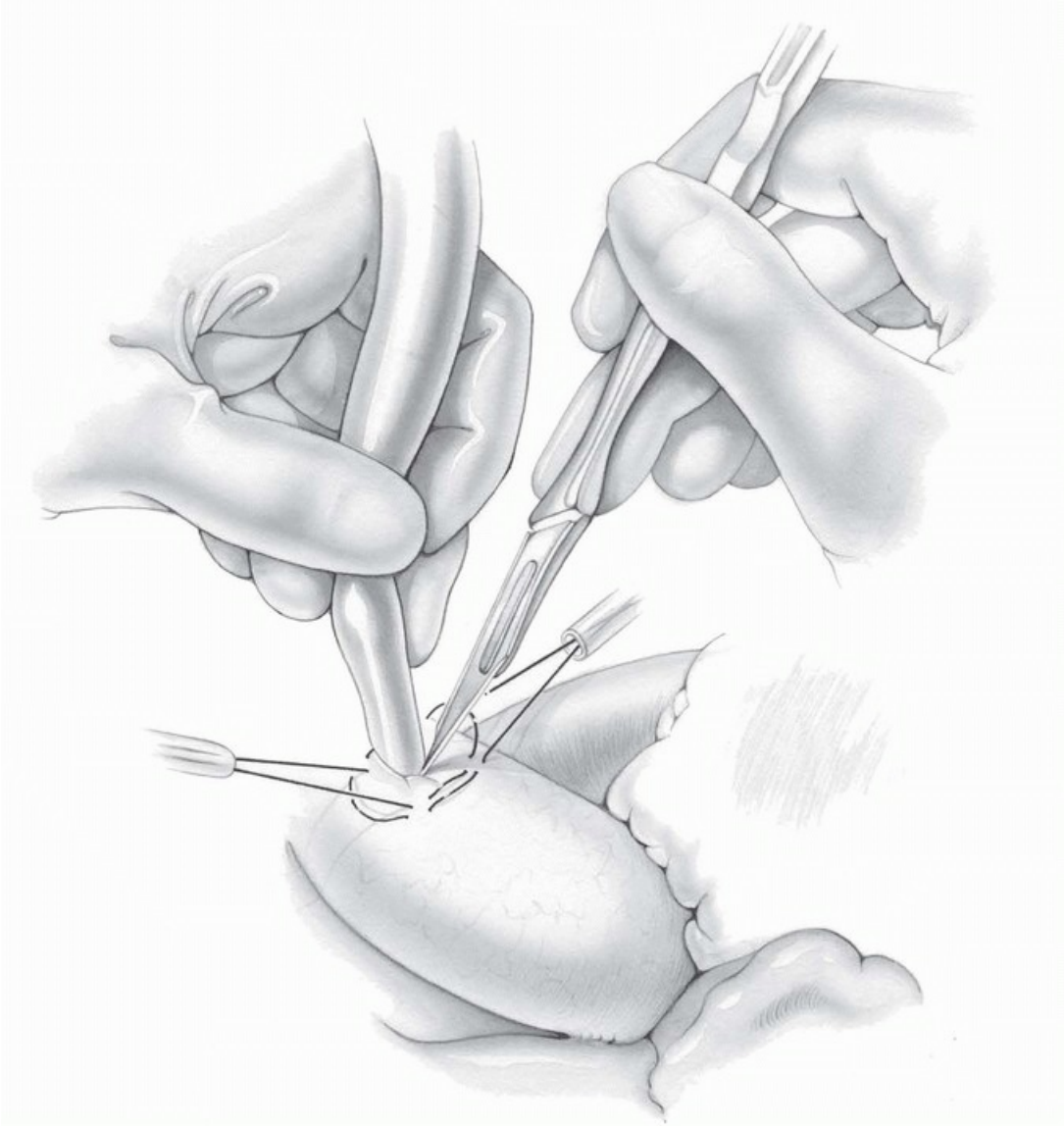

FIG. 2.9 Aortic cannulation.

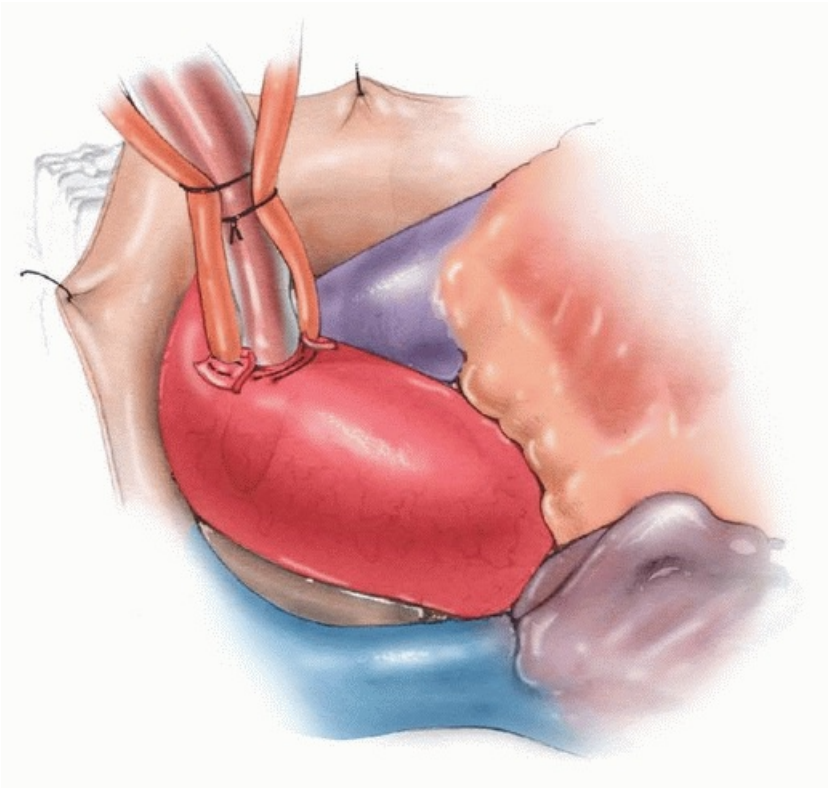

FIG. 2.10 Aortic cannulation, completed.

Femoral Artery Cannulation

Technique

The common femoral artery (or occasionally the external iliac artery) is dissected free for a short distance above the origin of the profunda femoris branch. Umbilical tapes are placed around the common femoral artery above the prospective cannulation site as well as the superficial and profunda arteries distally. Vascular clamps are applied to the femoral artery both above and below the intended arteriotomy site. The profunda artery may be either clamped or snared. A small transverse arteriotomy is made where the arterial wall appears to be relatively normal. A tapered cannula of appropriate size is then gently introduced through a transverse arteriotomy into the arterial lumen and is secured in place (Fig. 2.12A). Alternatively and more commonly, cannulation is performed through a purse-string using the modified Seldinger technique with serial dilations over a semi-stiff wire. The guidewire must be visualized within the descending aorta on echo before any dilation is performed. For closure, proximal and distal clamps are applied and the arteriotomy is closed with interrupted sutures.

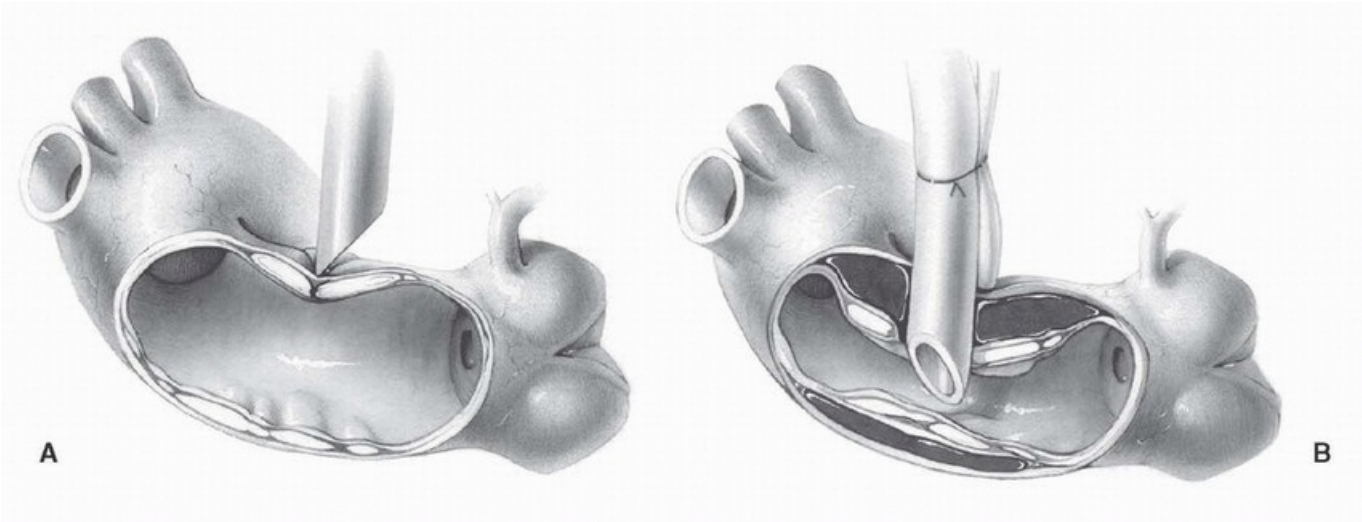

FIG. 2.11 Traumatic aortic wall dissection during introduction of a cannula.

Cannula Slippage

The perfusion pressure may cause the cannula to slip out. It should be secured by tying it to the umbilical tape already placed around the artery (Fig. 2.12B).

Cannula Injury to the Arterial Wall

The cannula tip may injure the arterial wall and cause separation of intimal plaque, which can result in retrograde aortic dissection (Fig. 2.13). The cannula must never be too large and should be introduced into the arterial lumen in an area that is relatively disease-free.

Limb Ischemia Due to Arterial Occlusion

The arterial cannula may occasionally occlude the entire arterial lumen and cause distal malperfusion. This problem is particularly common in younger patients with small arteries and little collateral flow. After cannulation, flow in the distal vessel or the foot should be evaluated using a Doppler. In cases of inadequate flow, a 5 French distal perfusion cannula is inserted distally using Seldinger technique and is attached to the side-arm of the arterial cannula (Fig. 2.14).

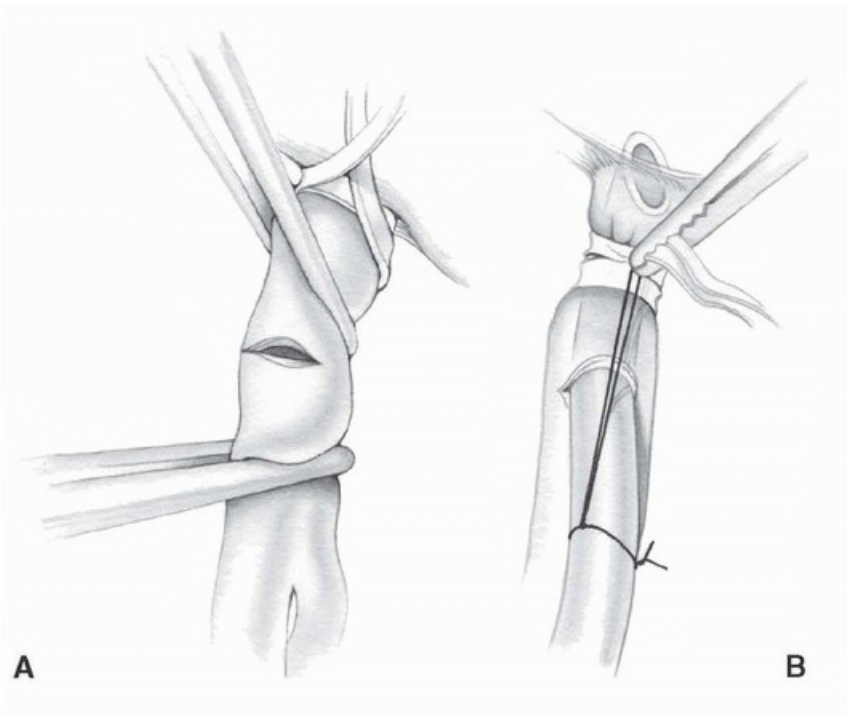

FIG. 2.12 Femoral artery cannulation. **A:** Transverse arteriotomy for introduction of the cannula. **B:** securing the cannula to the umbilical tape.

Injury to the Femoral Artery

A tourniquet or clamp used to tighten the umbilical tape around the proximal femoral artery and cannula may injure the wall of the artery. This can be avoided by placing a peanut sponge under the umbilical tape before tightening it.

Femoral Artery Dissection

The surgeon should always look for a column of pulsating blood in the femoral cannula; in the absence of obvious pulsation, it is very likely that the cannula tip is not in the lumen of the vessel.

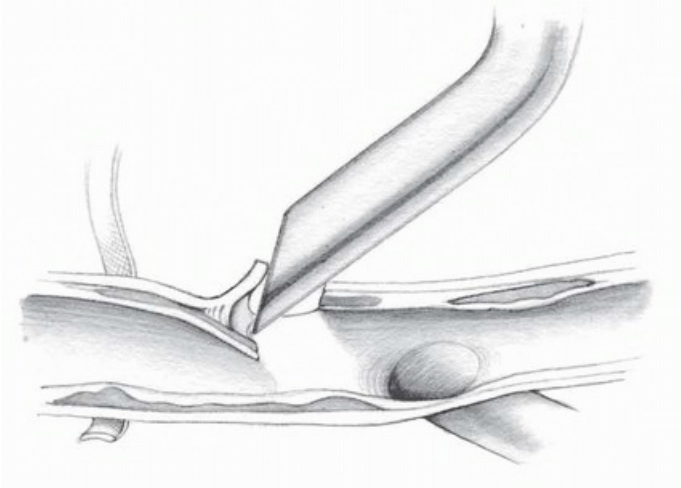

FIG. 2.13 Cannula injury to the common femoral artery causing retrograde aortic dissection.