Diaphragm Plication and Repair

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Introduction

Although symptomatic diaphragm paralysis and eventration differ in etiology and pathology, their treatment is the same: reduction of dysfunctional caudal excursion of the diaphragm during inspiration by plication. This basic strategy also is used for traumatic injuries or acquired hernia of the diaphragm. Minimally invasive diaphragm plication and repair techniques, such as laparoscopy and video-assisted thoracic surgery (VATS), have proved to be as effective and less morbid than the open approach via laparotomy or thoracotomy.

Wood, in 1916, was the first to perform surgery to reduce the dimension of the cupola of the diaphragm by wrinkling the diaphragm. In 1923, Morrison described the surgical principles that are still used today. He successfully repaired an eventration in a child by plicating the diaphragm. Bisgard, in 1947, precisely described surgical plication techniques used in a neonate. Since then, many studies have documented respiratory improvement after surgery. Various surgical techniques, such as plication, excision, and suturing using the thoracic or abdominal approach, have been evaluated. In 1996, Mouroux described a VATS technique to repair a diaphragmatic eventration thoracoscopically. Prospective studies showed that treatment of diaphragmatic eventration with VATS is a safe and effective alternative to conventional surgery. Functional improvement also persists on long-term follow-up. New data show a paradigm shift to a laparoscopic approach for surgically managing hemidiaphragmatic paralysis or eventration.

True diaphragmatic eventrations are congenital and based on defects in the muscular portion of the diaphragm. The muscular insertions are normal, the normal orifices are sealed, and there is no interruption of the pleural or peritoneal layers. Diaphragmatic eventrations are rare, with an incidence of less than 0.05 %; they are more common in males and more likely to affect the left hemidiaphragm. It is postulated that they occur embryologically because of abnormal migration of myoblasts from the upper cervical somites (C3) into two of the four embryologic structures that contribute to diaphragmatic development (the septum transversum and pleuroperitoneal membrane). The four structures are an unpaired ventral portion (septum transversum), two paired dorsolateral portions (pleuroperitoneal membranes), and an irregular medial dorsal portion (dorsal mesentery). Thomas and associates hypothesized in 1970 that myofibroblast ingrowth into the pleuroperitoneal membrane may be impaired when the abdominal viscera return to the peritoneal cavity prematurely. On the other hand, diaphragmatic paresis or paralysis is acquired and more common. It may be the result of abnormalities that affect the neuromuscular axis between the cervical spinal cord and the diaphragm. The most common cause is idiopathic tumor encroachment on the phrenic nerve or phrenic nerve trauma from cardiac surgery. Diaphragmatic paralysis also is more common in males and more likely to affect the left hemidiaphragm.

The goal of diaphragm plication is to improve dyspnea by reducing dysfunctional diaphragm excursion during inspiration, which is indicated only in symptomatic patients. An elevated hemidiaphragm per se is not an indication for operative intervention. It is suggested that patients with post–cardiac surgery phrenic nerve injury be observed for 1–2 years, because phrenic nerve function often improves during this period. If dyspnea is significantly impairing the patient's quality of life or cardiac rehabilitation, plication should be done after a short period of observation. Relative contraindications to diaphragm plication include morbid obesity and certain neuromuscular disorders (e.g., amyotrophic lateral sclerosis, muscular dystrophy). Morbidly obese patients should be evaluated for medical treatment or bariatric surgery before plication, as dyspnea may improve after significant weight loss. Patients with neuromuscular disorders should be

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approached with extreme caution. The benefits of plication are modest, and complications are common. Defects such as traumatic diaphragm rupture and symptomatic hiatal hernias are good indications for operative treatment.

The basic aim of plication and repair of the diaphragm is to provide satisfactory tension to and lowering of the diaphragm. Lowering of the cupola, while providing more physiologic tension, allows reexpansion of the adjacent lung, diminu-

Figure 47.1

Open transthoracic approach. Open transthoracic plication is the traditional approach to treating patients with symptomatic diaphragm eventration or paralysis. Most authors recommend a posterolateral thoracotomy through the sixth to eighth intercostal space (ICS). A variety of techniques for augmentation have been described, including hand-sewn U- stitches, mattress sutures, running sutures, and stapling devices, with or without mesh reinforcement. The direction of the plication (transverse or anteroposterior) is determined by the grossly apparent axis of the eventration. Generally, plication is performed according to a transverse axis (**a**). Two Babcock forceps raise the slimmed cupola, creating a fold. This fold is fixed at its base with a series of U-shaped nonabsorbable stitches ("flag" plication). The plicated area is folded onto the portion of the diaphragm that appears weaker and fixed close to the intercostal insertion of the diaphragm by one or several rows of sutures, creating a three-layer augmentation at the level of the weakened portion. Mechanical stapling at the base of the fold has been replaced by the U-stitches. Another technique to reinforce the weak portion of the diaphragm is the "accordion" plication, often performed by pediatric surgeons (**b**). In this technique, mattress sutures are placed in an anteromedial to posteromedial direction, creating the appearance of an accordion. The diaphragm may be plicated with as many rows of sutures as necessary to tighten it. It may be helpful to apply pledgets to the final layers to prevent the sutures from being torn out. If there is a defect or hernia, or the membrane of the diaphragm is very thin, mesh reinforcement may be considered. Significant short- and long-term improvement in dyspnea and respiratory function, as well as patient satisfaction, has been shown after open transthoracic plication. However, thoracotomy and single-lung ventilation are required but may be prohibitive in patients with multiple comorbidities and marginal functional status. *a*, *b*, *c* and *a*, *b* refer to the order of surgical steps tion of the adverse effects of abdominal pressure, elimination of paradoxic movements of mediastinal shift, and improvement in function of the intercostal and accessory muscles. Symptomatic defects must be closed by plication or ordinary suturing in a tension-free manner. If there is a defect in the muscular portion that cannot be closed without tension, reinforcement with mesh may be necessary. Different approaches to plication and repair of the diaphragm have been described.

Figure 47.1

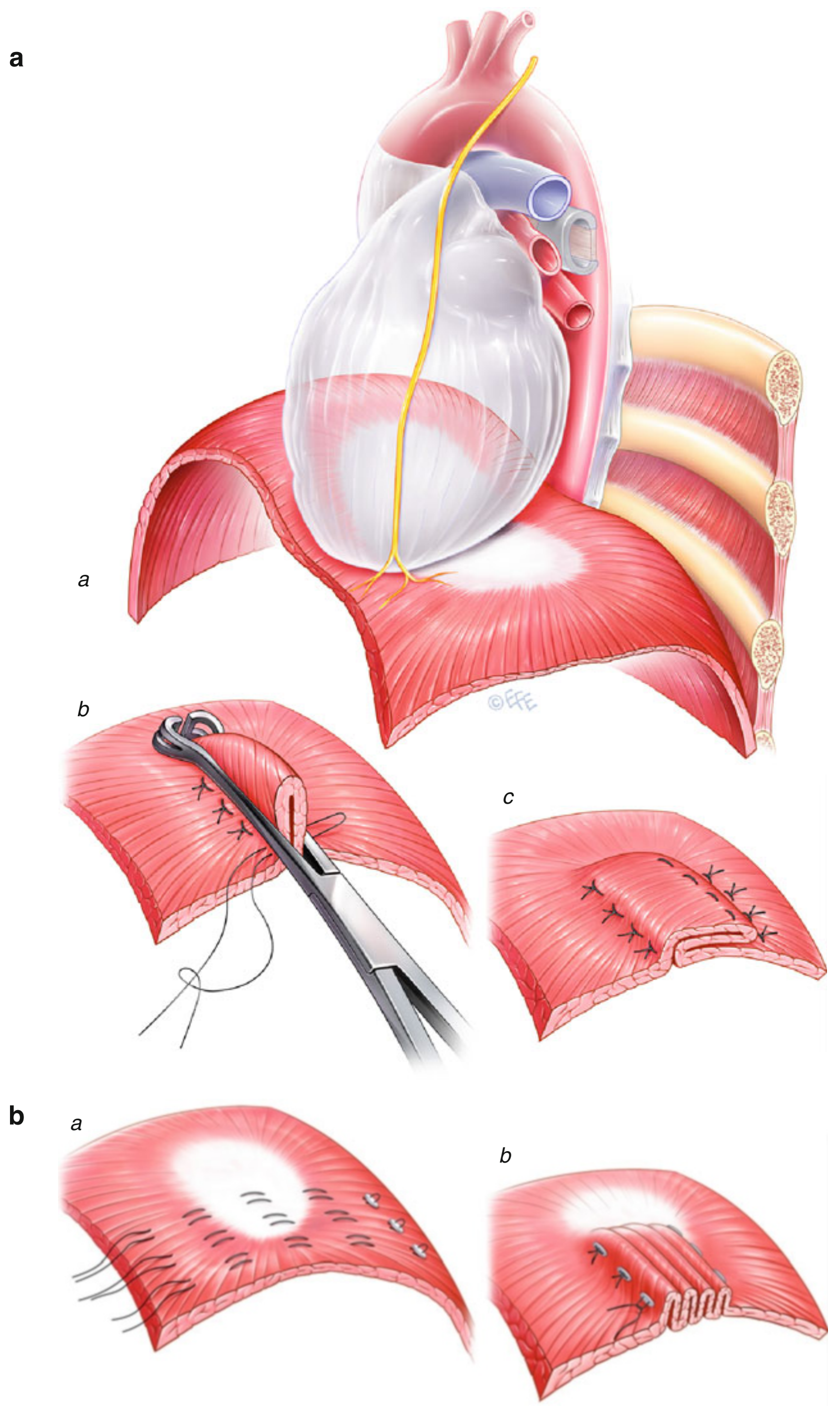


Figure 47.2

Thoracoscopic approach (VATS). An alternative approach is thoracoscopic plication by VATS, which may be performed with a minithoracotomy using three or four access ports. An example of this surgical technique is shown here. General anesthesia is provided via double-lumen intubation. The patient is placed in the full lateral position indicated for standard posterolateral thoracotomy. Two Thoracoports (10- or 5-mm; Covidien, Mansfield, MA) are placed in the fifth ICS on the posterior axillary line (for the camera) and on the mammary line (for the grasper). A 4- or 5-cm minithoracotomy is made over the ninth ICS on the posterior axillary line for suturing the diaphragm (**a**).

Figure 47.2a

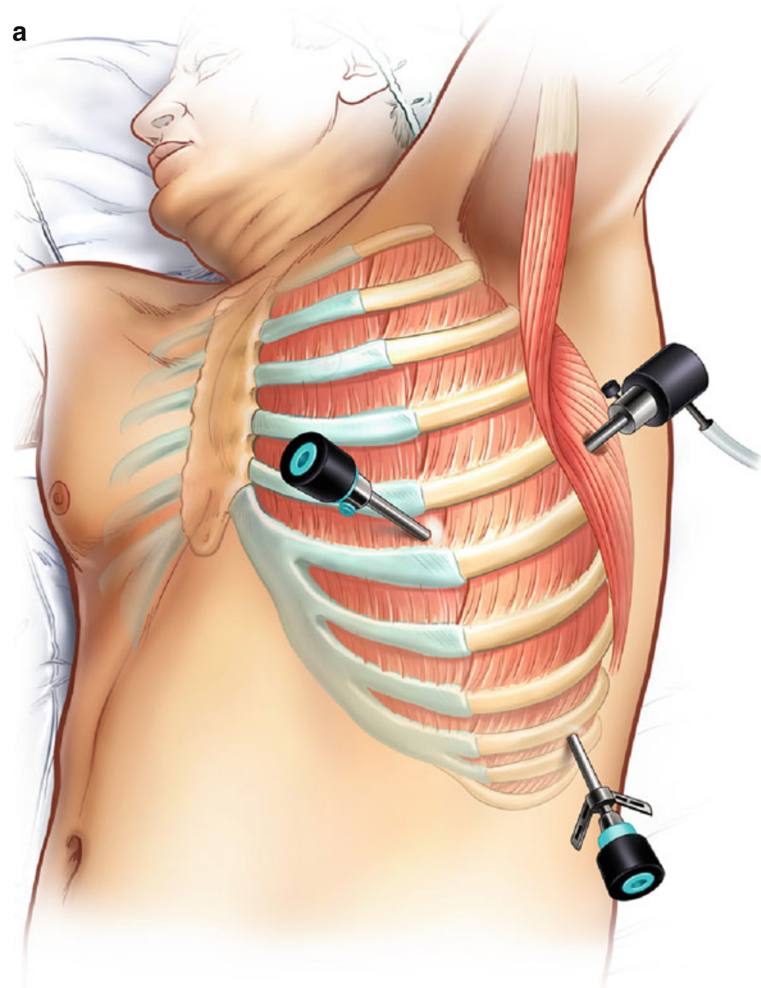


Figure 47.2 b-d

The apex of the eventration is grasped with a Babcock forceps and pushed down toward the abdomen (**b**). The created transverse fold is sutured with nonabsorbable material beginning at the periphery of the diaphragm close to the minithoracotomy with a running suture back and forth (**c**). The first continuous suture toward the cardiophrenic angle is placed superficially to avoid injury to the subdiaphragmatic organs. Once at the cardiophrenic angle, the sutures are drawn tight while the forceps used to push down the diaphragm is removed. A row of return stitches is made and tightened with the free end of the first knot. A second back-and-forth series of continuous sutures is placed similarly (**d**). If there is a defect in the muscular portion or the membrane of the diaphragm is very thin, mesh reinforcement may be considered. With regard to the open approach, several plication techniques have been described (continuous sutures, interrupted sutures, laparoscopic stapling). Thoracoscopic diaphragm plication is an excellent minimally invasive alternative to open transthoracic plication. The disadvantages of VATS are the required single-lung ventilation and the limited workspace

Figure 47.2b–d

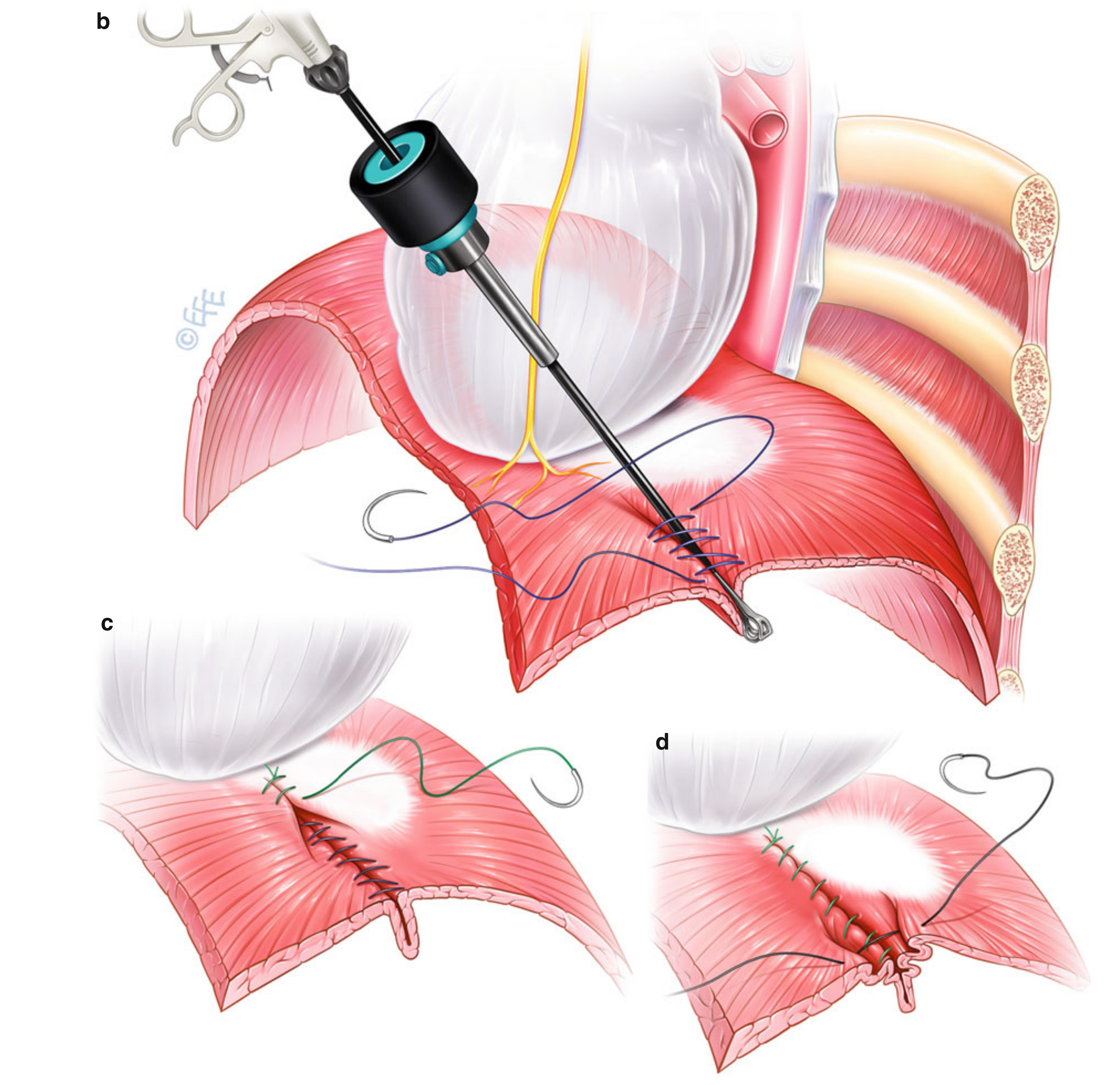


Figure 47.3

(**a**, **b**) Open transabdominal approach. Open transabdominal plication or repair of the diaphragm has been described for unilateral or bilateral diaphragmatic eventration, paralysis, or defects. It is performed over a median or transverse laparotomy. The diaphragm is grasped with two Babcock forceps, and a large transverse fold is drawn downward. The pleat is created with mattress stitches at the base, folded to the anterior circumference, and fixed frontally. A complication may be lung puncture with pneumothorax. Pleuropulmonary adhesions might make this approach unsuitable or even dangerous. Few outcome data are available on the results of open transabdominal plication in adults. Currently, it rarely is used. Advantages may be the laparotomy itself, which generally is less morbid than a thoracotomy; the elimination of the need for single-lung ventilation; and the access it provides to both sides of the diaphragm with one incision. Disadvantages are the difficult access to the posterior portion of the diaphragm and the higher morbidity associated with an open approach

Figure 47.3

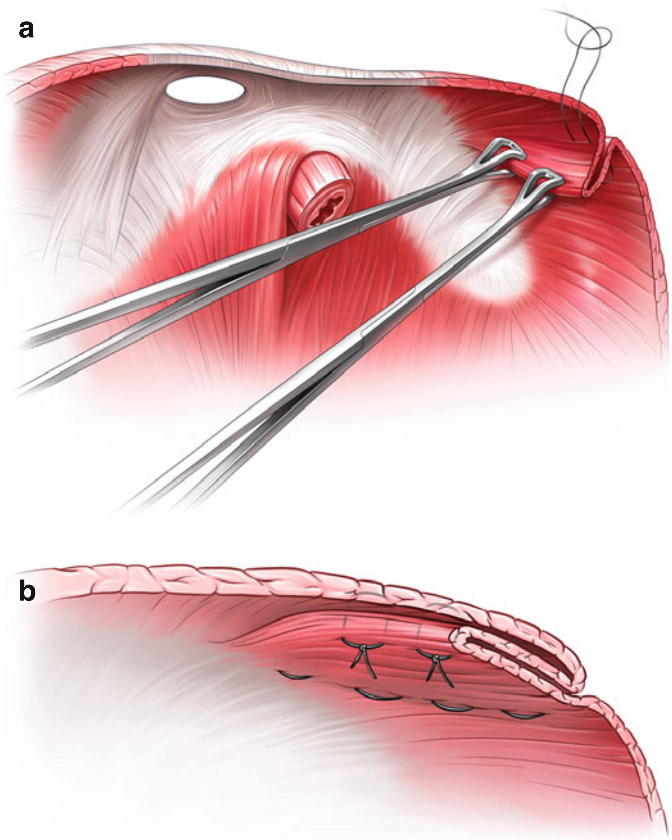
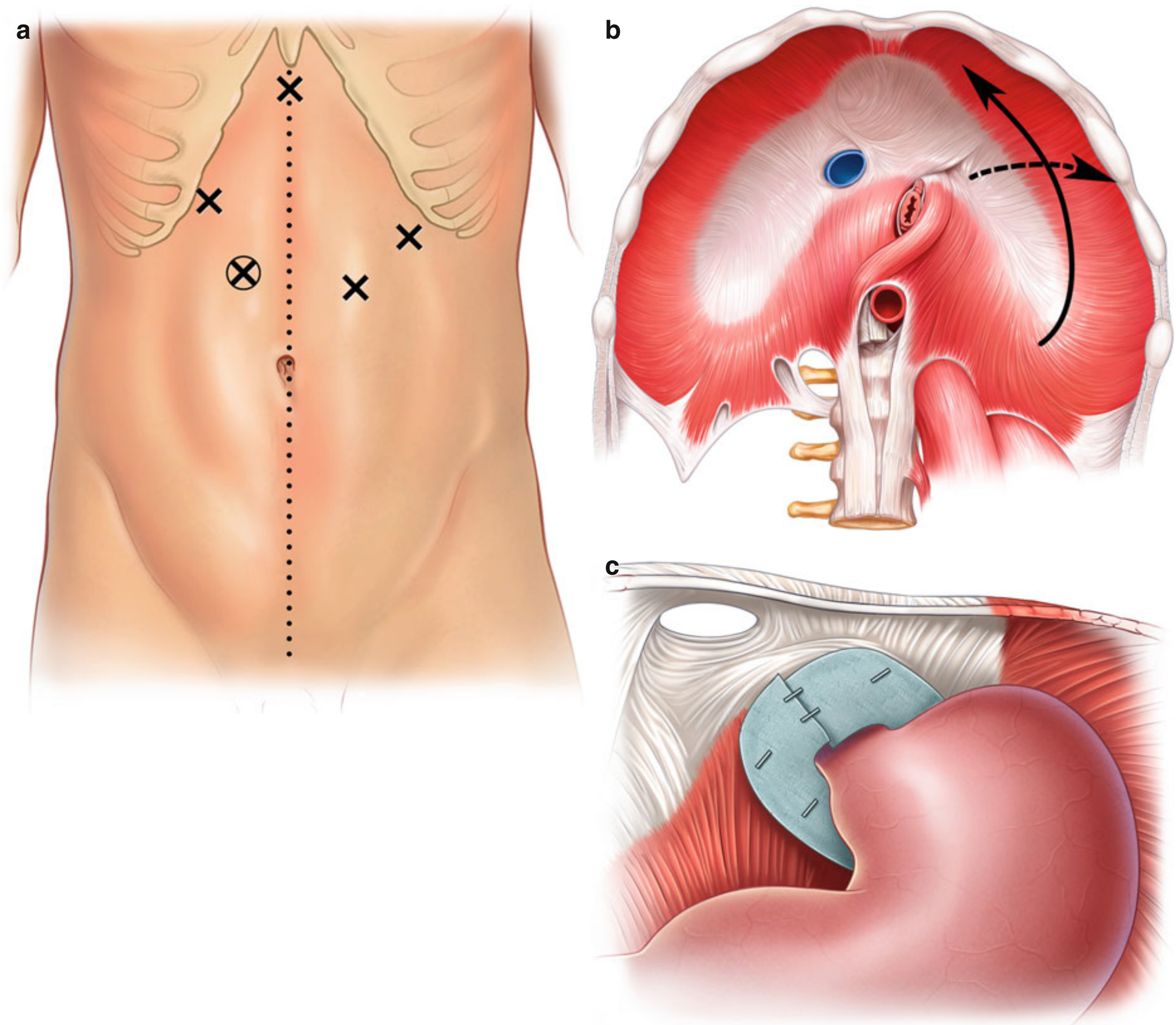


Figure 47.4

Laparoscopic approach. Laparoscopic diaphragm plication or repair offers several advantages. First, it avoids the intercostal nerve pain that often occurs after thoracotomy or thoracoscopy; second, it obviates the need for single-lung ventilation; and third, it provides good visualization and an adequate workspace. The procedure is done with a four-port-plus technique under general anesthesia via a single-lumen endotracheal tube with the patient in a 30° reverse Trendelenburg position. The surgeon is positioned between the legs of the patient, and two assistants are placed one at each side of the patient. First, a 12-mm port (for a 10-mm 30° camera) is placed 2 cm lateral to the midline about 10 cm from the xiphoid process (toward the contralateral side of the affected hemidiaphragm). Three additional working ports (two 10-mm and one 5-mm) are placed in a semicircle in the right or left middle and upper abdomen under visual control (**a**). If necessary for the left diaphragm, the left liver lobe is mobilized and a small incision is made close to the xiphoid process for the liver retractor to keep the left liver lobe away. For good access to the right diaphragm, the falciform ligament must be transected to allow the liver to drop slightly to provide access to the posterior portion of the right-sided hemidiaphragm. Pneumoperitoneum (12–15 mmHg) is established. A 5-mm defect is made in the affected diaphragm with electrocautery. The resulting capnothorax causes the diaphragm to drop down, making it easy to grasp. A chest tube is placed only if necessary. Transcutaneous retention stitches may create a fold for the suture. The plication is begun as posteriorly as possible on the diaphragm and proceeds posteriorly to anteriorly, then medially to laterally (**b**). A T-shaped plication is constructed with braided, nonabsorbable, no. 2 (curved needle), hand-sewn, pledget-reinforced U-stitches. The plication should be tight enough that adding more plicating stitches would cause damage to the repaired diaphragm. In some cases, if the membrane is very thin or a traumatic defect or a hernia is showing, mesh reinforcement of the diaphragm may be necessary. Long-term studies have shown that polypropylene mesh reinforcement increases the success rate for laparoscopic hiatal hernia repair without causing an additional complication burden (**c**). Therefore, it seems wise to use mesh reinforcement not only to reconstruct the dome of the diaphragm, but also to avoid undue tension on the repair and to prevent recurrence. Fixation of the mesh should be done with stitches or B-shaped hernia staplers. Pins are contraindicated because of the danger of cardiac tamponade

Figure 47.4



Conclusion

For the vast majority of patients, plication of the diaphragm results in an improvement in pulmonary spirometry, dyspnea, and functional status that endures over long-term follow-up. However, patients who are morbidly obese, have neuromuscular disorders, or have longstanding unilateral diaphragm paralysis may not realize the same benefit from plication. Studies directly comparing the various diaphragm plication techniques do not exist. The short-term results of the transthoracic and transabdominal approaches are comparable. In 2009, Freeman and associates published a large study in which they performed transthoracic plication in 41 patients with symptomatic unilateral paralysis, 30 of the procedures via a thoracoscopic approach (4-year follow-up). Plication resulted in significant improvements in dyspnea scores and pulmonary function tests (PFTs). Minimally invasive approaches may show less morbidity than the open approaches, with comparable functional results. The choice of plication technique also is based on the surgeon's training and preference. If a (traumatic) defect or hernia exists, tension-free closure of the diaphragm is necessary. For large defects, reinforcement with polypropylene mesh may be considered. Although routine mesh reinforcement to reduce the recurrence rates of diaphragm eventration is questionable, it seems wise to use mesh to reconstruct the dome of the diaphragm and to avoid undue tension on the repair if the membrane is very thin.

The morbidity and mortality rates of minimally invasive diaphragm plications, especially the laparoscopic approaches, are comparable with those of the open approaches. Conversion rates of the minimally invasive methods (VATS, laparoscopic approach) are low (<5 %). Complications reported for plication and repair of the diaphragm are pneumonia, pleural effusions, abdominal compartment syndrome, conversion to open surgery, abdominal viscus injury, deep venous thrombosis, stroke, upper gastrointestinal hemorrhage, pulmonary emboli, arrhythmia, and acute myocardial infarction. Very rare but serious complications in patients undergoing mesh reinforcement of the diaphragm, such as cardiac tamponade, may be avoided by using adequate fixation techniques. Laparoscopic diaphragm plication, in particular, seems to offer many advantages (e.g., avoidance of single-lung ventilation, ample working space and visualization, potentially less postoperative pain, reduced risk of visceral injury) and therefore should be favored. This procedure was first described by Hüttl and associates in 2004 in a series of three patients who had significant improvement in dyspnea and PFTs. A larger series of 25 patients who underwent laparoscopic diaphragmatic plication in a retrospective review (Groth et al. 2010) showed improved short- and mid-term (1-year follow-up) results in respiratory quality of life and PFTs. However, VATS approaches also are reasonable. For example, right-sided traumatic injuries of the diaphragm may be treated easily by thoracoscopy, which provides even better visualization and obviates the need to mobilize the liver. On the other hand, left-sided traumatic injuries of the diaphragm can be treated more easily via laparoscopy. The abdominal organs can be pushed down, and closure of the diaphragm is safe. For large hernias, routine use of mesh reinforcement of the diaphragm is recommended to achieve a tension-free repair.

Diaphragm plication is indicated only for symptomatic patients with diaphragmatic paralysis or eventration. Minimally invasive plication seems promising, showing good short-term and possibly also long-term results. Traumatic defects, giant hiatal hernias, and symptomatic hiatal or diaphragm hernias are good indications for minimally invasive repair. A variety of open, minimally invasive thoracic and transabdominal techniques have been described. In selecting the appropriate technique, surgeon training and preferences should be considered.

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