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SURGICAL ENDOSCOPY
and Other Interventional Techniques

Laparoscopic diaphragmatic hernia repair

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Abstract
Background: Adult-congenital diaphragmatic hernias and chronic traumatic diaphragmatic hernias are uncommon entities that are often technically challenging to repair. There is growing experience with a minimal access approach to these defects.
Methods: We reviewed the English-language literature using a MEDLINE search for "diaphragmatic hernia" and "laparoscopy."
Results: We found 19 case reports of laparoscopic adult-congenital diaphragmatic hernia repair. Reported complications included two enterotomies, one of which required conversion to laparotomy. We also found 11 case reports of laparoscopic chronic traumatic diaphragmatic hernia repair, with no reported complications or recurrences. Average operative time was 98 min, and average length of stay was 4.5 days. All reports claimed that there was less postoperative pain and an earlier return to full activity with the laparoscopic approach. Herein we discuss anatomy, pathophysiology, diagnosis, method of repair, and recurrence.
Conclusion: Adult-congenital diaphragmatic hernia and chronic traumatic diaphragmatic hernia are amenable to laparoscopic repair. Although experience is still limited, laparoscopic repair appears safe and is associated with a shorter hospital stay.

Key words: Diaphragmatic hernia — Laparoscopy — Congenital diaphragmatic hernia — Trauma

In recent years, extensive experience has been gained with the laparoscopic approach to the diaphragm. However, this experience has dealt almost exclusively with various types of hiatal hernia repair. Traumatic and congenital diaphragmatic defects are much less common, and each presents unique obstacles to a minimally invasive approach. However, with the proper training and equipment, most of the unusual diaphragmatic hernias are amenable to laparoscopic repair. Furthermore, patients can expect the same well-known benefits of minimal-access surgery, with a recurrence rate similar to the open approach.

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Anatomy and embryology

The diaphragm is a dome-shaped musculotendinous structure separating the thoracic and abdominal cavities. Its embryology is complex and not yet fully understood. The diaphragm is formed by the septum transversum, pleuroperitoneal membranes, dorsal mesentery of the esophagus, and body wall muscles [30]. During its caudal migration, the septum transversum passes the third, fourth, and fifth segments of the neck, where it is joined by what will become the phrenic nerve [30].

The right phrenic nerve enters directly lateral to the caval opening into the central tendon. The left phrenic enters directly lateral to the left border of the heart and in front of the central tendon into the muscular part of the diaphragm. The intradiaphragmatic branching of the phrenic nerves is fairly constant and must be considered when incising or suturing the diaphragm.

The pericardiophrenic, musculophrenic, and superior phrenic arteries are smaller vessels supplying the cranial side of the diaphragm. Small direct branches from the aorta also supply the dorsal diaphragm. Most of the blood flow comes from the inferior phrenic arteries, which arise from the aorta or celiac axis just below the median arcuate ligament [30]. The venous drainage can be variable, but it tends to follow the arteries.

The diaphragm contains well-defined openings for the esophagus, vena cava, and aorta, as well as several areas of potential herniation. The foramen of Bochdalek posterolaterally and the foramen of Morgagni and Larrey on either side of the xiphoid process are two common areas of congenital herniation. Rarely, congenital hernias, which are difficult to explain embryologically, occur in the pleuroperitoneal, peritoneo-peri-cardial, and paracaval areas [30].

Table 1. English-language case reports of laparoscopic repair of Morgagni-Larrey

First author (yr) [ref.]	Age (yr)	Defect size (cm)	Sac removed	Mesh	Complication
Kuster (1992) [16]	67	—	no	no	no
Rau (1994) [29]	42	6	yes	yes	no
Newman (1995) [23]	57	—	yes	yes	no
	22	—	yes	no	no
	70	10 × 15	yes	no	no
Smith (1995) [34]	60	2 × 3,5	no	no	no
Fernandez-Cebrian (1996) [11]	53	10 × 15	yes	no	no
Huntington (1996) [13]	32	4 × 9	no	yes	no
Orita (1997) [25]	78	2 × 4	no	yes	no
Vanclooster (1997) [37]	42	10 × 4	no	yes	no
Contini (1999) [5]	85	7 × 4	no	no	Enterotomy
Nguyen (1998) [24]	38	5 × 6	yes	yes	no
Bortul (1998) [3]	61	6 × 10	no	yes	Postop A-fib
Del Castillo (1998) [7]	50	12 × 15	no	yes	no
Ramachandran (1999) [27]	58	8 × 5	no	yes	no
Lima (2000) [18]	3	10 × 5	no	no	no

The crura arise from the anterior longitudinal ligament, intervertebral discs, and the anterior surface of L1 to L4 on the right and L1 to L2 or L3 on the left [32]. In 90% of cadavers, the crura were found to be tendinous posteriorly and medially from their vertebral origins to the level of T10 [12]. When suturing the crura, the tendinous portion as well as the endoabdominal fascia must be incorporated in the closure for adequate strength.

The diaphragm is the chief respiratory muscle in the body, with both inspiratory and expiratory functions. On fluoroscopy, diaphragmatic excursion is 3–6 cm in 75% of patients, <3 cm in 23%, and >6 cm in 2% [39]. In addition to having a slightly greater excursion, the left hemidiaphragm also moves more rapidly [39].

Congenital diaphragmatic hernias

Congenital hernias of the diaphragm can be classified into four different types—eventration of the diaphragm, posterolateral hernia of Bochdalek, parasternal hernia of Morgagni-Larrey, and peritoneopericardial hernia [30]. However, the term "congenital diaphragmatic hernia" usually refers to the most common posterolateral type of hernia, first described by Bochdalek in 1848. Development of a Bochdalek type hernia occurs at 8–10 weeks of gestation due to failure of closure of the posterolateral aspect of the pleuroperitoneal canal [32]. This anomaly is invariably associated with pulmonary hypoplasia and pulmonary hypertension, with persistent fetal circulation leading to respiratory failure in the neonatal period. Repair of the diaphragmatic defect is usually performed in the postnatal period after improvement in pulmonary function and reversal of pulmonary hypertension. Laparoscopic diaphragmatic repair is generally not feasible in these infants because of the risk of pneumoperitoneum. However, 5% of patients with Bochdalek hernias have small defects that are detected after the neonatal period [32].

In addition to two cases of thoracoscopic repair, three attempts at laparoscopic repair have been reported in the English-language literature [1, 38]. Al-Emadi et al. described the laparoscopic repair of a Bochdalek hernia in a 38-year-old woman presenting with acute epigastric pain [1]. Two defects were found in the left hemidiaphragm and closed with polytetrafluoroethylene mesh. Van der Zee and Bax described a primary laparoscopic repair in a 6-month-old boy [38]. Mar Fan et al. attempted the laparoscopic repair of an incarcerated Bochdalek hernia in a 32-year-old woman, but the procedure was converted to laparotomy when an enterotomy was suspected [20].

Unlike the Bochdalek hernia, the Morgagni-Larrey hernia is usually not symptomatic in the neonatal period and may present in adulthood with visceral incarceration. The defect occurs between attachments of the diaphragm to the xiphoid process and the seventh costal cartilage. This retro-xiphoid space is termed "Larrey's gap" on the left and "Morgagni's gap" on the right; it is normally filled with the superior epigastric vessels and fat. In asymptomatic patients, the defect is often discovered on a routine chest radiograph or CT scan performed for other reasons. Symptomatic patients may present with signs of visceral incarceration and are diagnosed with a CT scan, MRI, or contrast study. Surgical repair is usually indicated even in asymptomatic patients because of the risk of incarceration [40]. Repair can be achieved via a transabdominal or transthoracic approach. Thanks to recent advances in minimally invasive surgery, laparoscopic repair of these hernias can now be performed. Kuster et al. carried out the first laparoscopic repair of a Morgagni hernia in 1992 [16]. A total of 16 cases of laparoscopically repaired Morgagni hernias have been reported in the literature (Table 1).

Morgagni hernias often have a sac that may be quite adherent to the pleura and pericardium, making sac excision difficult. In two-thirds of the reported cases, the hernia contents were reduced and the defect repaired without excision of the sac. Whether or not this influences long-term recurrence or cyst formation is still uncertain because experience in this area is limited and there is a lack of objective long-term follow-up. In a case reported by Ramachandran and Arora, repair of the hernia without excision of the sac led to almost complete disappearance of the sac on CT scan 1 month after repair [27].

A second area of controversy is the method of defect closure. Small defects can generally be sutured laparoscopically. However, to avoid tension, defects >20–30 cm^2 should probably be closed with a prosthetic. Although several different prosthetic options are currently available, there is a dearth of comparative data [17]. We have relied on products that encourage fibroblastic ingrowth while resisting adhesion formation.

Traumatic diaphragmatic hernias

Penetrating trauma accounts for >90% of diaphragmatic injuries in the United States. The diaphragm is lacerated in 10%–15% of penetrating thoracic injuries and 0.8%–1.6% of patients with blunt trauma [2]. Unrecognized diaphragmatic rupture may occur in as many as 66% of patients with polytrauma [39]. Spontaneous closure of a rupture does not occur, however, omental interposition may seal a tear temporarily [39]. Therefore, the identification of a diaphragmatic defect is an indication for repair. Ruptures tend to occur at the central tendon or at the boundary between the tendinous and muscular part of the diaphragm. In blunt trauma, the rupture occurs on the left 65–85% of the time, on the right 15–35% of the time, and bilaterally 1–12% of the time [12, 39]. Reasons for the disparity are protection of the right side by the liver, underdiagnosis on the right, and weakness of the left hemidiaphragm at points of embryonic fusion of the pleuroperitoneal canals.

Although acutely herniated viscera may closely mimic a tension pneumothorax, diaphragmatic injury alone rarely causes hemodynamic compromise. Symptoms of acute injury include dyspnea, orthopnea, and chest or scapular pain. Blunt trauma is often associated with significant concomitant injury; in fact, one-third of these patients present with hypotension and hypoxia [39]. Blunt diaphragmatic injuries are associated with a 40% incidence of pelvic fractures, a 25% incidence of both hepatic and splenic injuries, and a 5% incidence of thoracic aortic tears [2]. Demetriades et al. reported a 75% incidence of associated intraabdominal injury with penetrating injury to the diaphragm [8].

Several diagnostic modalities may be used to identify a diaphragm injury, including chest radiography (with or without contrast studies), ultrasound, CT scan, and MRI. Laparoscopy and thoracoscopy have also been used successfully. Thoracoscopy does not require insufflation and has a sensitivity and specificity approaching 100% [15]. Unfortunately, only one hemidiaphragm can be inspected at a time, and there is no way to evaluate accompanying abdominal injury. It may be best suited for right-sided penetrating injuries <3 cm [15].

The role of laparoscopy in the evaluation of the acutely injured patient is still evolving. The disadvantages include the need for general anesthesia, the risks of access, gas embolism, and tension pneumothorax. However, several authors have confirmed the safety and efficacy of laparoscopy for both the diagnosis and repair of acute injuries [10, 14, 41]. Good candidates would be hemodynamically stable, without obvious evidence of serious intraabdominal injury (protruding viscera, peritoneal signs, blood in the gastrointestinal tract) and would have had only minimal prior abdominal surgery. Zantut et al. reported the results of 510 diagnostic laparoscopies for penetrating injury at three trauma centers [41]. No peritoneal penetration was found in 277 patients (54%), who were thus spared laparotomy. In 26 patients, a therapeutic procedure was performed laparoscopically, including 16 diaphragm repairs. Fabian et al. performed diagnostic laparoscopy on 182 patients with both penetrating and blunt trauma and found 11 diaphragm injuries (6%) [10].

Most laparoscopic diaphragm repairs have been done in the acute setting. The typical scenario involves a penetrating injury for which laparoscopy is used as a diagnostic tool. Trauma surgeons, whose laparoscopic experience tends to be variable, often perform the procedure. Primary repair is the rule, it can be accomplished with staples, running sutures, or interrupted sutures. Defects >25 cm^2 usually require prosthetic repair or repositioning of the diaphragm [19]. In either case, the injuries associated with such a high level of trauma would most likely preclude a laparoscopic approach.

In cases of acute injury, the supine position is used most commonly because it allows for a thorough abdominal exploration. Cougard et al. reported that visualization was improved and the reduction of herniated organs was easier when they used the lateral position in seven patients with acute diaphragm injury [6]. However, no abdominal exploration done in these cases. This position should be reserved for patients in whom several days have passed since their injury and who therefore do not require a proper diagnostic procedure. If the patient's condition permits, pneumatic compression stockings are used for thromboembolism prophylaxis. A wide surgical preparation from the neck to the knees is performed. The chest must always be included in the surgical field in case urgent anterolateral thoracotomy or tube thoracostomy is required.

A 30–45° angled laparoscope is essential for adequate visualization. At least two other working ports will be needed for suturing; one of them should be ≥10 mm to allow introduction of a large curved needle. Alternatively, 5-mm ports may be used with canoe-shaped needles. Additional 5-mm working ports should be placed without hesitation to allow for retraction of the various abdominal organs. Ports should be placed ≥5 cm or — more optimally — 10 cm away from each other to minimize "swordfighting."

There are no data favoring interrupted over running sutures, permanent over absorbable sutures, or two-layer over single-layer closure. Our preference is to use a braided permanent suture in either running or interrupted fashion, depending on the size and location of the defect. Polyglactin probably absorbs too quickly. Silk, polypropylene, and polydioxanone are easily damaged by the laparoscopic instruments.

Table 2. English-language case reports of laparoscopic repair of chronic traumatic diaphragmatic hernias

First author (yr) [ref.]	Location size (cm)	Time from injury	Operative time (min)	Type of repair
Pross (2000) [26]	Left/10	2 yr	145	Polydiaxone patch, pledgets
Meyer (2000) [22]	Right/—	10 yr	125	Nonabsorbable 0 mattress sutures
Torresini (2000) [36]	Left/7	6 mo	45	Mersilene mesh, endo clips
Matz (2000) [21]	Left/5	2–6 mo	40	Primary repair
	Right/10	2–6 mo	60	PTFE patch
	Left/4	2–6 mo	90	Primary repair
Shah (2000) [31]	Left/6	23 mo	160	PTFE patch
Slim (1998) [33]	Left/12	13 mo	—	Polypropylene patch
Domene (1998) [9]	Left/12	12 mo	—	Primary repair
Rasiah (1995) [28]	Left/5	5 wk	90	Primary repair
Campos (1991) [4]	Left/7.5	21 yr	—	PTFE patch
Average	7.9	3.5 yr	98	

Table 3. English-language case reports of laparoscopic repair of chronic traumatic diaphragmatic hernias

First author (yr) [ref.]	Perioperative complications	Length of stay (days)	Follow-up
Pross (2000) [26]	None	7	2 mo
Meyer (2000) [22]	None	6	42 mo
Torresini (2000) [36]	None	—	—
Matz (2000) [21]	Trocar site hernia	3	18 mo
	None	5	18 mo
	None	7	18 mo
Shah (2000) [31]	None	2	6 mo
Slim (1998) [33]	None	7	3 mo
Domene (1998) [9]	None	5	—
Rasiah (1995) [28]	None	2	18 mo
Campos (1991) [4]	None	1	1 wk
Average		4.5	

Pneumothorax is an obvious and recognized complication of laparoscopic diaphragm repair. When present, symptoms are usually minimal and can be improved by lowering the insufflation pressure and adding positive end-expiratory pressure. In 510 laparoscopies, Zantut et al. had four cases (0.8%) of tension pneumothorax [41]. Tension pneumothorax occurred in one of the 24 laparoscopically diagnosed diaphragm injuries reported by Fabian et al. [10]. Ivatury et al. encountered one tension pneumothorax in 17 patients with diaphragmatic defects that had been found on diagnostic laparoscopy [14]. All of these patients were diagnosed immediately and responded to tube thoracostomy decompression without sequelae. However, these cases demonstrate the need to maintain vigilance and have a ready course of action. Pneumothorax has not been reported in the laparoscopic repair of chronic diaphragmatic hernias, possibly secondary to the presence of intrathoracic adhesions.

Concern has also been raised over the potential for gas embolism in patients with acute trauma who may have liver or vascular injuries. Clinically apparent gas embolization is rare, occurring in only 15 of 115, 253 gynecologic laparoscopies [35]. Patients undergoing the repair of acute diaphragmatic injuries may be at increased risk due to a low central venous pressure and the need for reverse Trendelenberg positioning. However, gas embolization has yet to be reported in laparoscopy for trauma. In Fabian et al.'s study, there were 27 liver injuries and three major vascular injuries without evidence of embolization [10].

Chronic diaphragmatic hernias

Unlike acute injuries where minimal dissection is required, chronic defects often have intense fibrosis between the hernia sac, pleura, and abdominal viscera. Dissection planes are often difficult to discern, and there is a far greater chance of injury to the herniated abdominal organs, lung, and mediastinum [31]. Consequently, at the time of this writing, there are only 11 reports of successful repair in the English-language literature (Tables 2 and 3).

In repairs of chronic traumatic diaphragmatic hernias, positioning and port placement depend on the location and size of the defect. For most defects, a modified lithotomy position with the surgeon between the legs is usually best. An optical port is placed four finger breadths below the costal margin and several centimeters off midline, depending on the hernia's location, taking care to avoid the superior epigastric vessels. The true lateral position has also been reported to give adequate exposure [6]. As with congenital hernias, prosthetic mesh should be used to close larger defects in a tension-free manner. Although data on complications and recurrence are limited, preliminary results are very favorable. No recurrences after the laparoscopic repair of a chronic diaphragmatic hernia have been reported.

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