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Diaphragmatic Relaxation Incisions: Clinical Evidence and Surgical Technique

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Rezumat

Inciziile diafragmatice de relaxare: dovezi clinice și tehnica chirurgicală

Introducere: Inciziile diafragmatice de relaxare reprezintă un artificiu tehnic important în managementul chirurgical al herniilor hiatale mari şi complexe, în special atunci când apropierea primară a pilierilor diafragmatici nu poate fi realizată fără o tensiune excesivă. În ciuda progreselor în chirurgia minim invazivă a tehnicilor de întărire cu plasă, repararea herniilor hiatale continuă să fie asociată cu o rate semnificative de recidivă, atribuite în principal persistenței tensiunii axiale şi radiale la nivelul hiatusului esofagian.
Metodă: Acest articol analizează raționea fiziopatologică, tehnicile chirurgicale, rezultatele clinice şi complicațiile potențiale asociate inciziilor diafragmatice de relaxare. Au fost decrise atât incizii de relaxare pe partea dreaptă, cât şi pe partea stangă a hiatusului esofagian, fiecare având particularități anatomice distincte, avantaje tehnice şi limitări potențiale. Managementul defectului diafragmatic rezultat rămâne controversată, în special în ceea ce privește alegerea optimă între plasele biologice şi cele sintetice, precum şi profilul lor de siguranță pe termen lung. În plus prezentăm o analiză retrospectivă a opt pacienți cu hernii paraesofagiene complexe care au fost beneficiat de tratament chirurgical prin abord laparoscopic utilizând incizii de relaxare diafragmatică, ilustrând indicațiile practice, procesul decizional tehnic şi rezultatele clinice pe termen scurt asociate acestei abordări.
Rezultate: Deşi inciziile de relaxare facilitează în mod fiabil închiderea hiatusului fără tensiune şi îmbunătățesc fezabilitatea intraoperatorie, dovezile actuale sugerează că impactul lor asupra ratei de recidivă pe termen lung rămâne limitat atunci când sunt utilizate izolat. Prin urmare, complicațiile potențiale, inclusiv hernierea transdiafragmatică, pleurezia şi evenimentele adverse legate de plasă, trebuie luate în considerare cu atenție în tactica chirurgicală.

Concluzii: În ansamblu, inciziile diafragmatice de relaxare nu trebuie considerate o soluție de sine stătătoare, ci mai degrabă o componentă a unei strategii chirurgicale individualizate, care poate include de asemenea, întărirea selectivă cu plasă, gastropexia şi procedurile de alungire a esofagului la pacienții selectați corespunzator.

Cuvinte cheie: incizii diafragmatice de relaxare, incizii diafragmatice drepte şi stângi, întărirea hiatusului cu plasă, repararea laparoscopică a herniei hiatale, recidiva herniei hiatale, complicații asociatei plasei, plasă sintetică versus biologică, dimensiunea defectului hiatal

Abstract

Background: Diaphragmatic relaxing incisions represent an important technical adjunct in the surgical management of large and complex hiatal hernias, particularly when primary crural approximation cannot be achieved without excessive tension. Despite advances in minimally invasive surgery and mesh reinforcement techniques, hiatal hernia repair continues to be associated with substantial recurrence rates, largely attributed to persistent axial and radial tension at the esophageal hiatus.
Methods: This article reviews the pathophysiological rationale, surgical techniques, clinical outcomes, and potential complications associated with diaphragmatic relaxing incisions. Both right- and left-sided relaxing incisions have been described, each presenting distinct anatomical considerations, technical advantages, and potential limitations. Management of the resulting diaphragmatic defect remains controversial, particularly regarding the optimal choice between biologic and synthetic mesh and their long-term safety profiles. In addition, we present a retrospective analysis of eight patients with complex paraesophageal hernias who underwent laparoscopic repair using diaphragmatic relaxing incisions, illustrating the practical indications, technical decision-making process, and short-term clinical outcomes associated with this approach.
Results: Although relaxing incisions reliably facilitate tension-free hiatal closure and improve intraoperative feasibility, current evidence suggests that their impact on long-term recurrence remains limited when used in isolation. Potential complications, including transdiaphragmatic herniation, pleural effusion, and mesh-related adverse events, must therefore be carefully considered during surgical planning.
Conclusions: Overall, diaphragmatic relaxing incisions should not be regarded as a standalone solution but rather as one component of an individualized surgical strategy that may also include selective mesh reinforcement, gastropexy, and esophageal lengthening procedures in appropriately selected patients.

Keywords: diaphragmatic relaxing incisions, right- and left-sided incisions, hiatal mesh reinforcement, laparoscopic hiatal repair, hernia recurrence, mesh-related complications, synthetic vs biological mesh, hiatal defect size

Introduction

The first elective surgical repair of a hiatal hernia was reported by Angelo Soresi in 1919 (1). Growing interest in this pathology paralleled the development of radiological imaging, which substantially improved diagnostic accuracy (2). Subsequently, Rudolph Nissen established the abdominal approach combined with fundoplication as the cornerstone of surgical treatment (3,4). In 1950, Richard Sweet introduced the transthoracic approach, adapting principles derived from inguinal hernia repair, and later reported favorable outcomes in more than 100 patients (5,6). Philip Allison and Norman Barrett further contributed to the refinement of hiatal hernia surgery and to the understanding of its close relationship with gastroesophageal reflux disease (7).

The initial evolution of hiatal hernia surgery was dominated by the concept of anatomical restoration. Surgical treatment focused primarily on reducing the herniated stomach, restoring the normal anatomy of the esophageal hiatus through crural approximation, and securing the stomach below the diaphragm by various forms of gastropexy. Although this approach improved anatomical reconstruction, long-term functional outcomes remained suboptimal, prompting a reassessment of surgical strategy.

The modern surgical approach integrates two complementary principles. The first preserves the importance of anatomical reconstruction by reducing the herniated stomach, restoring the diaphragmatic hiatus through crural repair, and re-establishing fixation of the stomach within the abdominal cavity. The second emphasizes restoration of the antireflux

barrier through fundoplication and reconstruction of the angle of His, thereby improving the competence of the esophagogastric junction and increasing the intra-abdominal pressure gradient acting on the distal esophagus. Together, these concepts form the basis of the contemporary techniques developed by Belsey, Skinner, Hill, and their successors (8).

From the outset, broad consensus has existed regarding three fundamental principles of hiatal hernia repair: complete reduction of the hernia, restoration of an adequate intra-abdominal esophageal length, and achievement of a tension-free hiatal closure (9,10).

The primary objective is the complete reduction of the hernia, which is essential for achieving an optimal surgical outcome.

The second is the reduction of axial tension by ensuring sufficient intra-abdominal esophageal length through extensive mediastinal mobilization or, when necessary, esophageal lengthening procedures such as Collis gastroplasty (11,12).

The third is the reduction of radial tension to allow secure, tension-free suturing of the diaphragmatic crura (13).

Although the objectives of hiatal hernia repair are widely accepted, the optimal technical approach to achieving them remains controversial. Two parallel directions have consequently evolved. One focuses on the development of novel surgical adjuncts intended to improve the durability of hiatal reconstruction, whereas the other re-evaluates previously described techniques that were gradually abandoned despite a sound pathophysiological rationale (14,15). Among these technical adjuncts, diaphragmatic relaxing incisions have recently regained interest as a valuable option for facilitating tension-free crural closure in patients with large or complex hiatal defects (16, 17).

Objectives

The primary objective of this study was to evaluate the role of diaphragmatic relaxing incisions in the surgical management of complex paraesophageal hernias by presenting a retrospective series of eight patients who underwent laparoscopic repair using this technique. Particular emphasis was placed on their effectiveness in achieving tension-free hiatal closure, their contribution to anatomical reconstruction, and the technical considerations guiding the choice between right-sided and bilateral relaxing incisions. In addition, the study aimed to critically review the current literature regarding the pathophysiological rationale, surgical techniques, clinical outcomes, and potential complications associated with diaphragmatic relaxing incisions, with particular focus on their impact on recurrence rates and their relationship with prosthetic mesh reinforcement.

Methods

The present study consists of two complementary components: a retrospective analysis of a consecutive series of patients who underwent laparoscopic paraesophageal hernia repair using diaphragmatic relaxing incisions, and a review of the current literature addressing the role of this technique in hiatal hernia surgery.

The clinical analysis included eight patients who underwent laparoscopic repair of large or complex paraesophageal hernias with the use of diaphragmatic relaxing incisions. All procedures were performed by the same surgical team using a standardized operative technique. Patient selection included individuals with large type III or type IV paraesophageal hernias, as well as patients undergoing surgery for recurrent hiatal hernias. Although the underlying diagnoses were heterogeneous, all patients shared the same intraoperative characteristic that constituted the focus of the present study: significant morphological alteration of the diaphragmatic crura, preventing tension-free hiatal closure by conventional approximation. The decision to perform a diaphragmatic relaxing incision was based on intraoperative visual and tactile assessment demonstrating excessive radial tension during attempted crural suturing following complete mediastinal esophageal mobilization.

Postoperative clinical follow-up was performed at 1, 6, 12, and 24 months. Objective evaluation of anatomical recurrence was systematically assessed at 12 and 24 months using barium swallow examination and/or contrast-enhanced CT in all patients, regardless of symptom status.

To place our clinical experience into perspective, a review of the literature was also performed to evaluate the current evidence regarding diaphragmatic relaxing incisions in the surgical management of paraesophageal hernias. A systematic search was conducted in PubMed, PubMed Central, the Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, UpToDate, EMBASE, and MEDLINE Complete (EBSCO). The search strategy included the following terms: ("hiatal hernia" OR "paraesophageal hernia") AND (relaxing OR "crural incision" OR "crural release" OR "tension relieving" OR "diaphragmatic incision"). The search was limited to studies published between January 2000 and December 2025.

Studies were considered eligible if they included adult patients undergoing hiatal or paraesophageal hernia repair and reported outcomes related to

diaphragmatic or crural relaxing incisions. Non-English publications, duplicate reports, case reports including fewer than five patients, studies without separate data regarding relaxing incisions, and articles lacking relevant clinical outcome data were excluded.

A total of 159 records were identified across the seven databases. After removal of 13 duplicate records and exclusion of 8 non-English publications, 138 records underwent title and abstract screening. Of these, 113 studies were excluded because they did not specifically address diaphragmatic or crural relaxing incisions in the setting of hiatal or paraesophageal hernia repair. Twenty-five full-text articles were assessed for eligibility. Following detailed evaluation, nine studies were excluded because they did not provide separate data on relaxing incisions (n = 4), represented duplicate publications of the same patient cohort (n = 2), included fewer than five patients (n = 2), or lacked relevant clinical outcome data (n = 1). Consequently, sixteen studies were included in the qualitative review.

Results

Our tertiary referral center specializes in the surgical management of both benign and malignant esophageal diseases. Between January 1st, 2010, and December 31, 2025, a total of 534 patients with hiatal hernias were evaluated, of whom 498 (93.3%) underwent surgical treatment. According to the SAGES classification (9), hiatal hernias were categorized into four types: type I (sliding), type II (pure paraesophageal), type III (mixed), and type IV, characterized by herniation of additional intra-abdominal organs into the thoracic cavity. Among this cohort, 107 patients presented with giant hiatal hernias, predominantly type III or type IV, defined by a hiatal defect larger than 5 cm on preoperative imaging. These patients required additional technical maneuvers to facilitate hiatal reconstruction and to minimize the risk of recurrence.

Case Series

Eight patients underwent laparoscopic paraesophageal hernia repair with diaphragmatic relaxing incisions. The decision to perform either a right-sided or bilateral relaxing incision was made intraoperatively according to the degree of crural tension and the structural integrity of the diaphragmatic crura. Right-sided relaxing incisions were performed in five patients in whom excessive tension was predominantly localized to the right crus, whereas bilateral relaxing incisions were required in three patients. All procedures were completed laparoscopically using a standardized operative technique.

Relaxing incisions were created using electrocautery with careful preservation of the pleura and phrenic nerve. In all eight patients, diaphragmatic relaxing incisions allowed tension-free crural reapproximation, facilitating secure hiatal closure. Hiatal reconstruction was achieved by suturing the diaphragmatic pillars using non-absorbable sutures, without prosthetic reinforcement of the hiatus. The diaphragmatic incision was covered with mesh to prevent herniation. No intraoperative complications attributable to the relaxing incision were encountered. Likewise, no early postoperative complications related to the relaxing incision, including diaphragmatic herniation or respiratory compromise, were observed during the postoperative hospital stay. Clinical and radiological follow-up including barium swallow studies, with a minimum duration of two years, demonstrated no evidence of early anatomical recurrence (defined as the presence of the stomach, gastroesophageal junction, or other abdominal viscera above the diaphragm on barium swallow or computed tomography) or procedure-related morbidity in any patient. Although limited by the small sample size and retrospective design, the present case series illustrates the technical feasibility of diaphragmatic relaxing incisions in selected patients with complex paraesophageal hernias requiring tension-free hiatal reconstruction.

All patients underwent comprehensive preoperative evaluation, including upper gastrointestinal endoscopy (EGD), contrast-enhanced computed tomography (CT), barium swallow (BS) examination, laboratory investigations, and high-resolution esophageal manometry.

Case 1 – Large type III paraesophageal hernia requiring right-sided diaphragmatic relaxing incision: A 68-year-old man presented with a large type III paraesophageal hiatal hernia. Preoperative EGD demonstrated a 5-cm hiatal defect with Cameron erosions and displacement of the gastroesophageal junction 4 cm above the hiatus. CT imaging revealed a 10-cm craniocaudal mixed hernia, with 50% of the stomach herniated intrathoracically. Following hernia reduction and circumferential mediastinal mobilization, persistent tension on the right crus precluded primary closure. A right-sided diaphragmatic relaxing incision successfully allowed tension-free posterior cruroplasty using non-absorbable sutures. A floppy Nissen fundoplication was constructed, and the resulting right diaphragmatic defect was covered with a polytetrafluoroethylene (PTFE) mesh to prevent transdiaphragmatic herniation. The postoperative course was uneventful, and clinical and radiological follow-up demonstrated no recurrence at two years.

Case 2 – Large paraesophageal hernia with severe reflux requiring right-sided diaphragmatic relaxing incision: A 74-year-old woman presented with severe gastroesophageal reflux symptoms secondary to an 11-cm paraesophageal hernia. Evaluation revealed a 6-cm hiatal defect with approximately 50% of the stomach displaced into the thoracic cavity. Intraoperatively, significant radial tension prevented primary crural reapproximation despite extensive mediastinal mobilization. A right-sided diaphragmatic relaxing incision facilitated successful medialization of the crura and a tension-free closure. Reconstruction was completed with a floppy Nissen fundoplication and meticulous vagal nerve preservation. The secondary diaphragmatic defect was reinforced with PTFE mesh. The postoperative recovery was uneventful, and follow-up at six months, one year, and two years confirmed durable anatomical reconstruction without recurrence or complications.

Case 3 – Recurrent type III paraesophageal hernia with fibrotic crura requiring right-sided diaphragmatic relaxing incision: A 59-year-old man presented with a recurrent type III paraesophageal hiatal hernia after a previous Nissen fundoplication and was scheduled for revisional laparoscopic surgery. Preoperative imaging confirmed a recurrent 5-cm hiatal defect. Following adhesiolysis and mobilization of the esofagogastric junction via disruption of the previous fundoplication, severe perihiatal fibrosis was encountered. The right diaphragmatic crus was markedly retracted and fibrotic, posing a high risk of tearing during primary closure. A right-sided diaphragmatic relaxing incision allowed adequate medialization and subsequent tension-free retroesophageal crural repair using non-absorbable sutures, eliminating the need for hiatal mesh reinforcement. A redo Nissen fundoplication was performed, and the relaxing incision defect was covered with a PTFE mesh. The postoperative course was uneventful, with no complications or anatomical recurrence identified at the 2-year assessment.

Case 4 – Giant type III paraesophageal hernia requiring right-sided diaphragmatic relaxing incision: An 82-year-old woman presented with a giant type III paraesophageal hiatal hernia. EGD showed a 6-cm hiatal defect with complete intrathoracic migration of the gastric fundus and partial migration of the body, accompanied by diffuse mucosal congestion. A CT scan revealed a 14-cm craniocaudal defect, with over 70% of the stomach herniated. Following hernia reduction and extensive mediastinal mobilization, severe radial tension from chronic stretching prevented secure crural reapproximation. To avoid crural disruption, a right-sided diaphragmatic relaxing incision was executed, enabling tension-free crural closure with non-absorbable sutures without hiatal mesh deployment. A Nissen fundoplication was constructed, and the relaxing incision defect was covered with a PTFE mesh. The patient experienced no postoperative complications and remained recurrence-free during the 2-year follow-up period.

Case 5 – Large type III paraesophageal hernia in an obese patient requiring right-sided diaphragmatic relaxing incision: A 65-year-old obese man was diagnosed with a large type III paraesophageal hiatal hernia. EGD showed a 5-cm hiatal defect with cephalad displacement of the gastroesophageal junction and chronic reflux changes. A CT scan demonstrated an 8–10 cm craniocaudal mixed hernia, with 35–40% of the stomach in the thoracic cavity. Intraoperatively, attempted crural closure revealed marked radial tension. A right-sided diaphragmatic relaxing incision was performed, permitting adequate crural medialization and tension-free suturing. A Nissen fundoplication was successfully performed, and the secondary diaphragmatic defect was covered with a PTFE mesh. Postoperative recovery was uneventful, without respiratory or gastrointestinal adverse events, and follow-up confirmed satisfactory functional recovery and no recurrence at 2 years.

Case 6 – Recurrent paraesophageal hernia with rigid crura requiring bilateral diaphragmatic relaxing incisions: A 71-year-old man presented with a recurrent paraesophageal hiatal hernia. EGD revealed a 6-cm hiatal defect with marked cephalad displacement of the gastroesophageal junction. A CT scan confirmed a recurrent (SAGES type III) hernia measuring 10 cm in the craniocaudal axis, with 45% of the stomach displaced superiorly. Following complete adhesiolysis, takedown of the previous fundoplication, hernia sac reduction, and extensive mediastinal mobilization, both diaphragmatic crura were found to be rigid. An initial right-sided relaxing incision provided insufficient tension relief during crural approximation. Consequently, a left-sided diaphragmatic incision was also performed, which successfully facilitated tension-free suturing of the pillars without hiatal mesh reinforcement. Both diaphragmatic defects were then covered with PTFE mesh. The postoperative course was entirely uneventful.

Case 7 – Recurrent paraesophageal hernia with severe cicatricial remodeling requiring bilateral diaphragmatic relaxing incision: A 76-year-old woman presented with a recurrent paraesophageal hiatal hernia requiring revisional laparoscopic surgery. EGD showed a 5-cm hiatal defect with chronic reflux changes, and a CT scan revealed a 9-cm craniocaudal hernia containing 50% of the stomach. Following adhesiolysis, hernia sac reduction, and circumferential

mediastinal mobilization, severe cicatricial remodeling and markedly reduced compliance of both crura prevented primary approximation. Bilateral diaphragmatic relaxing incisions were performed, achieving adequate bilateral crural medialization and tension-free hiatal closure. The normal anatomy of the esophagogastric junction was restored, ensuring adequate intra-abdominal esophageal length. Both diaphragmatic defects were covered with polytetrafluoroethylene (PTFE) mesh. The postoperative course was uneventful, without respiratory or gastrointestinal complications, and the patient remained recurrence-free at 2 years.

Case 8 – Type IV paraesophageal hernia with gastric and colonic herniation requiring bilateral diaphragmatic relaxing incisions: An 80-year-old man presented with a large type IV paraesophageal hiatal hernia. EGD showed a 7-cm hiatal defect with complete intrathoracic displacement of the gastric fundus and diffuse mucosal congestion. A CT scan demonstrated complete intrathoracic migration of the fundus along with partial herniation of the transverse colon. Following hernia reduction and extensive mediastinal esophageal mobilization, both diaphragmatic crura were found to be rigid and widely separated, precluding standard reapproximation. Bilateral diaphragmatic relaxing incisions were performed to achieve satisfactory crural medialization and tension-free hiatal closure. The repair was finalized with a floppy Nissen fundoplication and meticulous vagal preservation. The resulting bilateral diaphragmatic defects were covered with polytetrafluoroethylene (PTFE) mesh. The postoperative course was uneventful, and the patient recovered without respiratory or gastrointestinal complications, showing no evidence of recurrence on follow-up.

The findings from the present series suggest that the clinical decision to perform a diaphragmatic relaxing incision should not rely solely on the absolute size or anatomical classification of the hiatal hernia. Instead, this maneuver should be guided by a comprehensive intraoperative assessment of crural morphology and the persistent inability to achieve tension-free crural reapproximation despite optimal mediastinal mobilization of the esophagus (*Table 1* and *Table 2*).

Consequently, the clinical observations derived from this case series must be interpreted within the broader pathophysiological framework of complex hiatal reconstruction. The development of significant axial and radial tension following the reduction of giant paraesophageal hernias constitutes the primary biomechanical driver justifying the execution of diaphragmatic relaxing incisions. A thorough understanding of these biomechanical forces is therefore mandatory for precise patient selection and optimal intraoperative surgical decision-making. The subsequent section delineates these underlying pathophysiological principles and explores their direct surgical implications.

Pathophysiological Basis of Diaphragmatic Relaxing Incisions

The number of surgical procedures performed for hiatal hernia repair has increased substantially over the past three decades. Following reduction of the

Table 1. Clinical characteristics, intraoperative indications, and surgical management of the eight patients undergoing diaphragmatic relaxing incisions

Case	Age/Sex	Hernia type	Main intraoperative finding	Rationale for diaphragmatic relaxing incision	Incision	Outcome
1	68/M	Type III	Persistent right crural tension	Tension-free crural reapproximation could not be achieved	Right	Uneventful recovery
2	74/F	Large PEH	Persistent radial tension	Facilitation of tension-free crural closure	Right	Uneventful recovery
3	59/M	Recurrent Type III	Dense perihiatal fibrosis and retracted right crus during redo surgery	High risk of crural disruption during primary closure	Right	Uneventful recovery
4	82/F	Giant Type III	Chronic remodeling and stretching of the diaphragmatic crura	Marked radial tension preventing tension-free closure	Right	Uneventful recovery
5	65/M	Type III + obesity	Large hiatal defect with persistent radial tension	Tension-free crural closure not achievable by primary repair alone	Right	Uneventful recovery
6	71/M	Recurrent PEH	Severe cicatricial remodeling with markedly reduced diaphragmatic compliance	Bilateral crural insufficiency preventing secure closure	Bilateral	Uneventful recovery
7	76/F	Recurrent PEH	Severe cicatricial remodeling with markedly reduced diaphragmatic compliance	Persistent radial tension after redo dissection	Bilateral	Uneventful recovery
8	80/M	Type IV	Both diaphragmatic crura were found to be rigid and widely separated	Inability to achieve secure tension-free crural closure	Bilateral	Uneventful recovery

Table 2. Intraoperative indications for diaphragmatic relaxing incisions in the present series

Indication	No. of patients
Persistent radial tension	5
Redo surgery with severe perihiatal fibrosis	3
Giant hiatal defect (≥ 5 cm)	8

herniated stomach, reconstruction of the esophageal hiatus requires restoration of the hiatal defect by primary crural closure, with or without prosthetic reinforcement. However, the optimal method of hiatal repair remains controversial, largely because of the persistently high incidence of postoperative recurrence, despite the fact that most recurrences remain asymptomatic (9,10).

Axial tension can be readily assessed intraoperatively by measuring the length of the intra-abdominal esophagus. An intra-abdominal esophageal length of less than 2 cm suggests esophageal shortening (11), a finding that has important implications for surgical planning and may require an esophageal lengthening procedure.

In contrast, radial tension results from the lateral traction exerted by the diaphragmatic crura during hiatal closure. Chronic herniation produces a repetitive "piston effect" generated by cyclical transhiatal displacement of the stomach, leading to progressive remodeling and lateralization of the diaphragmatic crura. Following hernia reduction, the crura often remain fixed in this remodeled position, making tension-free crural reapproximation difficult and increasing the risk of suture failure and postoperative recurrence (*Fig. 1 A, B*).

The indication for diaphragmatic relaxing incisions should be guided by intraoperative assessment of radial tension rather than by the size or type of the hiatal hernia alone. Unlike axial tension, radial tension cannot be assessed using a standardized intraoperative method. In routine practice, its evaluation relies on the surgeon's visual and tactile assessment during attempted crural reapproximation, making objective quantification difficult (12,13). Consequently, the decision to perform a diaphragmatic relaxing incision remains largely dependent on intraoperative surgical judgment and individual experience rather than on validated quantitative criteria.

Bradley et al. (14) were the first to describe intraoperative measurement of hiatal tension using a laparoscopically calibrated tensiometer. Calibrated hooks were applied to the diaphragmatic crura during attempted reapproximation to measure the traction force required for hiatal closure. When excessive tension was identified, diaphragmatic relaxing incisions were performed to facilitate tension-free reconstruction.

Despite its conceptual appeal, intraoperative tensiometry has not been adopted into routine practice because it is technically demanding, prolongs operative time, and requires dedicated equipment. Consequently, hiatal reconstruction continues to rely primarily on intraoperative assessment of crural morphology, tissue quality, and radial tension. Although subjective, this approach remains the basis for selecting the reconstructive strategy. Accordingly, primary posterior crural suturing remains the standard technique, while diaphragmatic relaxing incisions serve as a valuable adjunct when tension-free crural closure cannot be achieved. Importantly, they should not be regarded as an alternative to primary crural repair, but rather as a technical adjunct that enables secure, tension-free crural closure.

Diaphragmatic Relaxing Incisions

Diaphragmatic relaxing incisions were first described in 1968 as a technical adjunct for reducing tension during hiatal hernia repair (16). Since then, they have been used to facilitate tension-free crural closure in both primary suture repair and mesh-reinforced reconstruction (16,17). However, several aspects of the technique remain controversial, including the optimal incision site (right versus left), management of the resulting diaphragmatic defect, and the choice of reinforcement material. Although right-sided relaxing incisions are

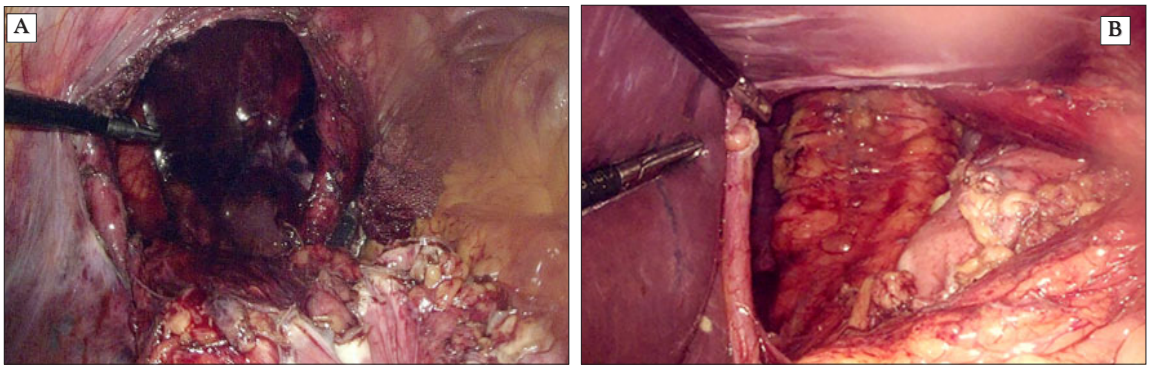


Figure 1. **(A)** Introperative image – recurrent hiatal hernia with a large hiatal defect. **(B)** Laparoscopic view demostrating a markedly widened hiatal orifice associated with substantial technical dificulty during primary crural closure.

most commonly performed because of their technical simplicity and lower perceived risk of phrenic nerve injury (18), full-thickness diaphragmatic incisions introduce a potential risk of postoperative transdiaphragmatic herniation. Consequently, routine mesh reinforcement of the resulting defect remains a matter of debate, balancing the prevention of herniation against the potential for mesh-related complications (19,20).

Right Diaphragmatic Incisions

The right-sided diaphragmatic relaxing incision is performed along the lateral border of the right crus, parallel to the inferior vena cava, while preserving an approximately 3-cm bridge of diaphragmatic tissue to facilitate secure mesh fixation when required. The incision is full-thickness and enters the right pleural cavity; therefore, meticulous dissection is required to prevent inadvertent injury, particularly when pleuropulmonary adhesions to the underlying lung are present.

The incision usually extends from the midportion of the right crus inferiorly but generally does not reach the aortic hiatus, as adequate crural reapproximation can usually be achieved without further extension. Excessive inferior dissection may increase the risk of thoracic duct injury (2). Greene et al. (17) favored the right-sided approach and routinely reinforced the resulting diaphragmatic defect with synthetic mesh.

Although the right-sided approach is most commonly used, it may not always be anatomically optimal. The right crus is often thinner and less robust than the left one, potentially limiting the degree of tension release achievable in patients with severe crural separation. Therefore, the choice of incision should be individualized according to intraoperative crural morphology and tissue quality rather than based solely on technical preference (*Fig. 2*).

Crespin et al. (22) reported 16 patients in whom diaphragmatic relaxing incisions were performed when tension-free crural reapproximation could not be achieved. A right-sided incision approximately 2 cm lateral to the crus was preferred, whereas left-sided or bilateral incisions were reserved for selected cases. Unlike most authors, they avoided intentional pleural entry. Hiatal repair consisted primarily of posterior crural suturing, supplemented with anterior sutures when necessary, followed by reinforcement of both the hiatal repair and the relaxing incision with a C-shaped biologic mesh secured by interrupted sutures and fibrin sealant.

Left Diaphragmatic Incisions

The left-sided diaphragmatic relaxing incision originates lateral to the esophageal hiatus and extends along the left hemidiaphragm while preserving a 1-2 cm cuff of diaphragmatic tissue along the costal margin. When greater tension release is required, the incision may be extended laterally to achieve adequate mobilization of the left hemidiaphragm. Particular attention should be paid to identification and preservation of the phrenic nerve, as injury may result in diaphragmatic paralysis and postoperative respiratory morbidity (*Fig. 3*) (14).

Yano et al. preferred the left-sided approach to minimize the risk of inferior vena cava injury (23). In their technique, the resulting diaphragmatic defect was reinforced with a 1-mm polytetrafluoroethylene (PTFE)

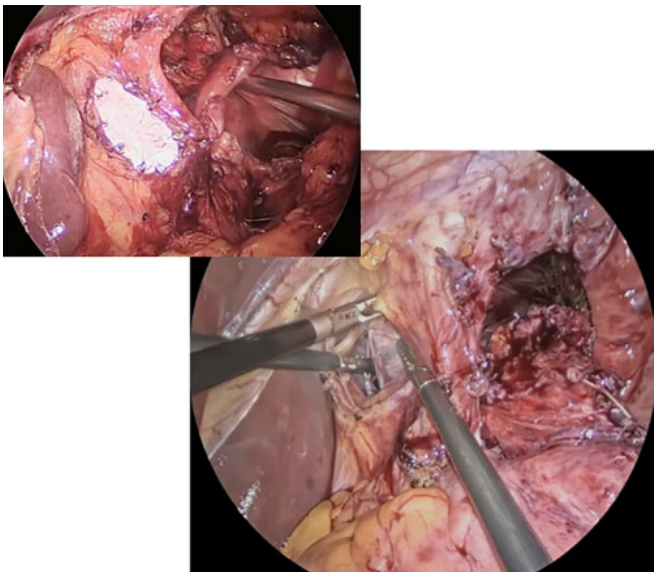


Figure 2. Incision of right diaphramatic crus. In the cartridge, covering of the diaphragmatic defect with prosthetic mesh (institutional clinical archive)

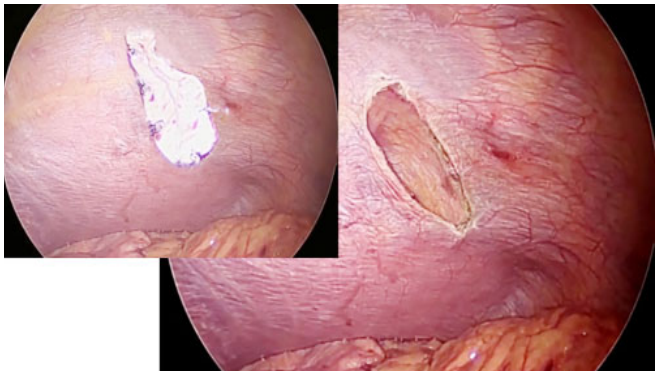


Figure 3. Intraoperative laparoscopic view. Left diaphragmatic incision, final aspect. In the cartridge, the operative step of dividing the diaphra matic muscle fibers. In cartridge: covering of left diaphragmatic incision with PTFE mesh

mesh (24). Although this approach provides substantial medialization of the left crus and facilitates tension-free crural reapproximation, it requires wide opening of the left pleural cavity and creates a large diaphragmatic defect that generally requires prosthetic reinforcement. Consequently, the procedure is technically more demanding and may increase the risk of postoperative transdiaphragmatic herniation, limiting its widespread adoption.

Large communications between the abdominal and pleural cavities are generally well tolerated during laparoscopic surgery, and routine pleural drainage is unnecessary in the absence of lung injury. When clinically significant pleural effusions occur, they can usually be managed successfully with image-guided pigtail catheter drainage (26).

Decision-Making Controversies

From a theoretical perspective, diaphragmatic relaxing incisions are justified when tension-free crural closure cannot be achieved. In clinical practice, however, both the indications and management of the resulting diaphragmatic defect remain controversial.

In our series, diaphragmatic relaxing incisions were performed in eight patients with hiatal defects larger than 5 cm. Nevertheless, hiatal defect size alone was not considered the primary indication. The decision was based mainly on intraoperative assessment of crural morphology and radial tension during attempted crural reapproximation. Thus, inability to achieve secure, tension-free crural closure, rather than hiatal defect size, represented the principal indication for this maneuver.

By reducing radial tension, diaphragmatic relaxing incisions facilitate secure, tension-free crural reapproximation (27). From a biomechanical perspective, they should be regarded as tension-releasing maneuvers rather than reconstructive procedures. Because the incision creates a secondary full-thickness diaphragmatic defect, appropriate management of this defect is an integral part of the procedure.

The optimal method of defect reconstruction remains controversial. While many authors advocate routine prosthetic reinforcement to prevent postoperative transdiaphragmatic herniation, others question its long-term benefit because of potential mesh-related complications. Consequently, the decision to cover the defect, as well as the choice of reinforcement material, should be individualized according to defect size, tissue quality, and intraoperative findings.

Synthetic mesh provides durable mechanical support but may be associated with erosion, fibrosis, chronic pain, and dense adhesions, particularly near the esophagus. Biologic mesh was introduced to reduce these complications and has shown favorable short-term safety (28), although its high cost and uncertain durability have limited its widespread use. Biosynthetic meshes represent an intermediate alternative, combining temporary mechanical support with gradual resorption, but long-term evidence remains limited (29). Among these, poly-4-hydroxybutyrate (P4HB) Phasix™ ST mesh with Sepra technology is designed to minimize adhesions before resorbing within 30 days, while the P4HB scaffold remains to provide temporary reinforcement while avoiding permanent prosthetic implantation.

Relaxing Incisions – Which Side?

Guided by the available literature, which generally favors the right-sided approach because of its technical simplicity and perceived safety, we preferentially performed right-sided diaphragmatic relaxing incisions whenever feasible, although no consensus regarding the optimal side has been established. Accordingly, right-sided incisions were performed in five patients, whereas bilateral incisions were required in three patients when unilateral tension release proved insufficient to achieve secure, tension-free crural reapproximation.

Although the theoretical advantages and disadvantages of right- and left-sided diaphragmatic relaxing incisions have been widely discussed, no objective criteria currently guide the choice of one approach over the other. Selection should therefore be individualized according to intraoperative anatomy, crural morphology, tissue quality, and the degree of residual radial tension following mediastinal esophageal mobilization.

In most patients, the space between the right crus and the inferior vena cava provides the most straightforward approach. When this space is limited or unsuitable, a left-sided relaxing incision may be preferred. Bilateral incisions should be reserved for cases in which unilateral tension release is insufficient to achieve secure, tension-free crural closure (13,16,21, 30).

A review of the literature reported right-sided relaxing incisions in 72% of patients, left-sided incisions in 22%, and bilateral incisions in 6% (24). This distribution probably reflects technical preference rather than a proven superiority of one approach. Overall, unilateral relaxing incisions reduce crural tension by approximately 46%, whereas bilateral incisions achieve a reduction of about 56% (14,31). Although these findings support the biomechanical rationale of the technique, whether they translate into lower long-term recurrence rates remains uncertain. In our experience, the side of

the relaxing incision was determined by intraoperative assessment of crural morphology rather than by a predetermined preference for either hemidiaphragm.

Coverage of the Resulting Diaphragmatic Defect

Regardless of whether the relaxing incision was unilateral or bilateral, the resulting diaphragmatic defect was consistently reinforced with a resorbable monofilament Phasix™ mesh (BD, Warwick, RI, USA).

There is broad agreement that the diaphragmatic defect created by a relaxing incision should be covered to prevent postoperative transdiaphragmatic herniation. However, the optimal covering material remains controversial because published series are small and direct comparative data are lacking. Unlike mesh reinforcement of the esophageal hiatus, covering a relaxing incision places the prosthesis at a distance from the esophagus, potentially reducing the risk of mesh-related complications. Early reports therefore successfully used permanent synthetic mesh without mesh-related morbidity (27). Nevertheless, no study has demonstrated the clear superiority of biologic, synthetic, or biosynthetic materials for this specific indication.

Crespin et al. (22) initially reinforced both right- and left-sided relaxing incisions with biologic mesh. Although right-sided repairs proved safe, two patients developed symptomatic transdiaphragmatic herniation after left-sided biologic reinforcement, requiring reoperation. The authors subsequently abandoned routine left-sided biologic reinforcement and recommended non-absorbable synthetic mesh whenever a left-sided relaxing incision was necessary (22,29). They attributed the more favorable outcome on the right side to the protective effect of the left hepatic lobe.

Permanent synthetic mesh placed directly at the esophageal hiatus has been associated with severe complications, including erosion and stenosis (*Fig. 4 A, B*)(33,34,35).

However, these complications appear less likely after covering diaphragmatic relaxing incisions because a bridge of diaphragmatic muscle separates the mesh from the esophagus. Overall, biologic mesh was used in 78% of reported cases and synthetic mesh in 22% (24). Although mesh-related complications were uncommon, herniation through the relaxing incision occurred in approximately 28% of patients, with no significant difference between biologic and synthetic reinforcement. Consequently, the optimal material for reinforcing diaphragmatic relaxing incisions remains to be established.

Relaxing Incisions – "Is It Enough?"

In patients who underwent diaphragmatic relaxing incisions, primary crural suturing was considered sufficient to achieve hiatal closure. The primary purpose of this maneuver was to avoid mesh reinforcement of the crural repair itself. Intraoperative assessment confirmed adequate tension relief, suggesting that durable hiatal closure could be achieved by primary suture.

Diaphragmatic relaxing incisions are technical adjuncts designed to relieve radial tension rather than definitive reconstructive procedures. The final repair still depends on achieving secure crural closure, with or without mesh reinforcement. Consequently, the independent contribution of relaxing incisions to reducing recurrence remains difficult to determine. Nevertheless, by facilitating tension-free crural

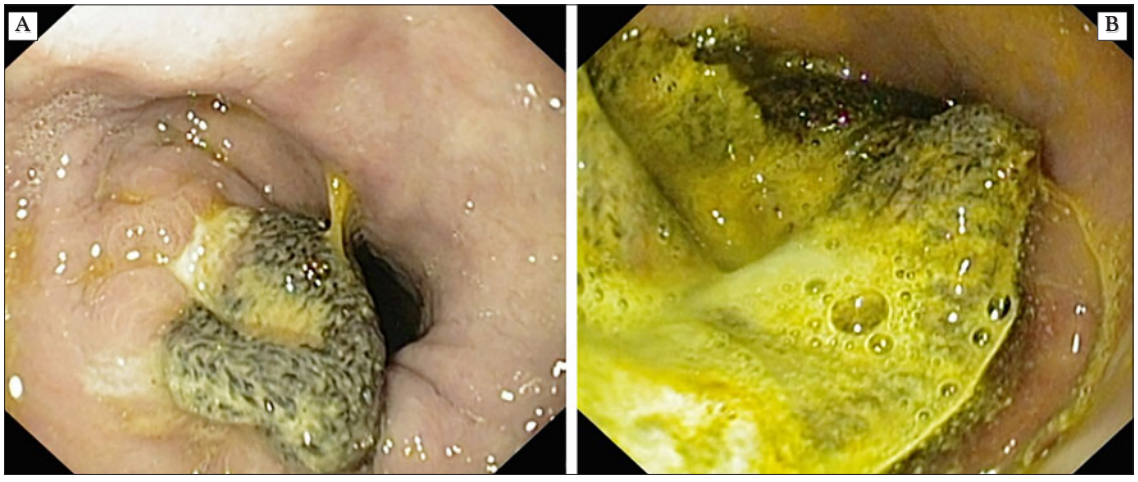


Figure 4. Upper digestive endoscopy. Notable erosion of the esophgeal wall with intraluminal mesh extrusion **(A** and **B)**

closure and, when necessary, mesh reinforcement under more favorable biomechanical conditions, they may improve the quality of hiatal reconstruction.

Published data indicate recurrence rates of approximately 58% after primary closure without tension-relieving maneuvers, 38% after biologic mesh reinforcement, and 56% after diaphragmatic relaxing incisions combined with biologic mesh (24). Most of the available evidence originates from meta-analyses. Therefore, the very small sample size of our cohort, together with relatively short duration of follow-up, warrants cautious interpretation of the results. These findings suggest that, although relaxing incisions facilitate crural closure, their

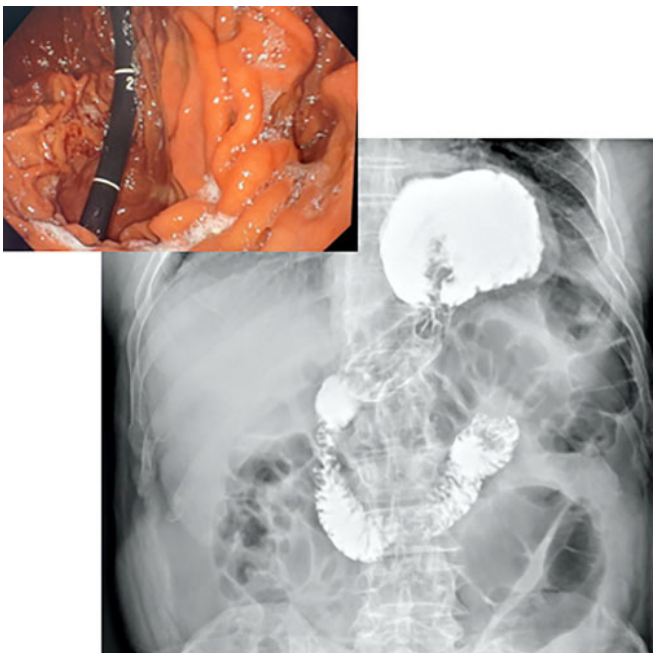


Figure 5. Barium Swallow- transverse (mesentero-axial) gastric volvulus. In cartridge: a large paraesophageal hernia is visualized with difficulty in engaging the endoscope at the level of gastric antrum(U turn view inside the herniated stomach



Figure 6. Barium Swallow- showing half of the stomac positioned above the diaphragm. In cartridge: upper digestive endoscopy- in U-turn, a giant paraesophageal hernia is visualized with hyperemia and mucosal friability at the level of the hernial neck

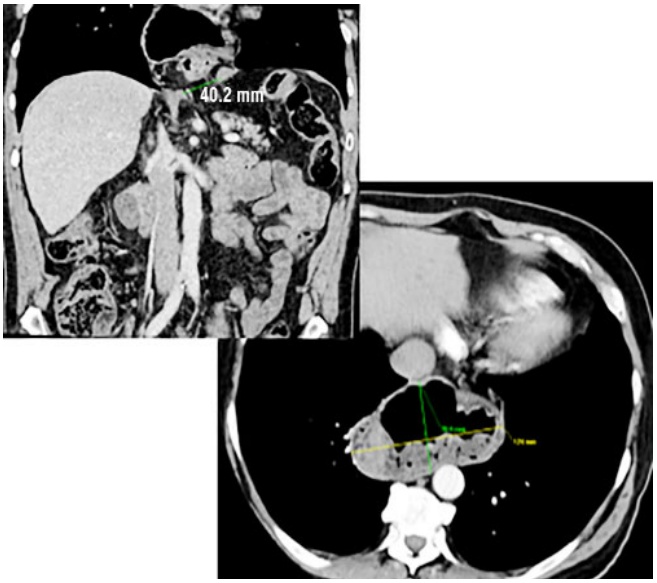


Figure 7. Coronal CT demonstrate voluminous recurrent paraesophageal hernia In cartridge: axial CT demonstrates a voluminous recurrent hiatal hernia

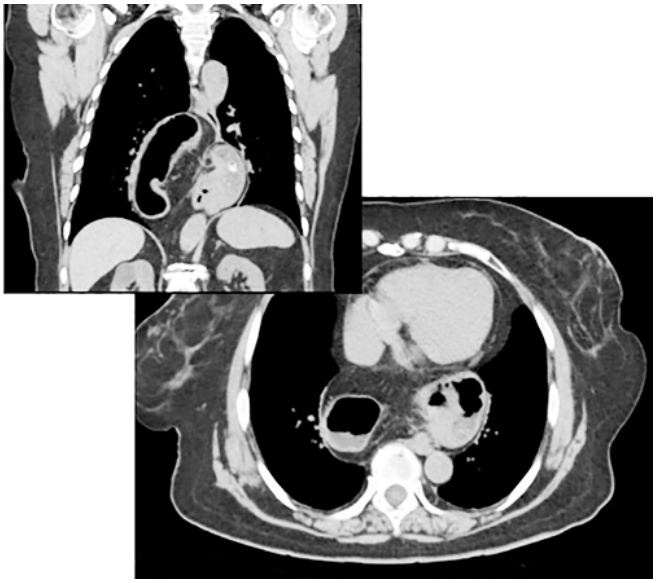


Figure 8. Coronal CT demonstrates intrathoracic migration of the stomach. In cartridge: axial CT- intrathoracic herniation of stomach

direct effect on long-term recurrence is limited (16). However, because few technical innovations in hiatal hernia surgery have substantially reduced recurrence rates, a technique supported by a sound biomechanical rationale should not be dismissed solely because its clinical benefit appears modest.

Discussions

Attempts to improve postoperative outcomes have led to the introduction of numerous technical adjuncts in the surgical management of large hiatal hernias (*Figs. 5, 6, 7, 8*).

Mesh reinforcement, using synthetic, biologic, or biosynthetic materials, has become the most extensively investigated strategy for achieving tension-free hiatal repair. However, marked separation of the diaphragmatic crura may preclude tension-free primary closure, leaving mesh reinforcement as the only option for completing the repair.

Nevertheless, mesh-reinforced cruroplasty offers both advantages and disadvantages. The inflammatory and fibrotic response associated with mesh implantation may result in esophageal stenosis, abscess formation, or fistula development. A recent meta-analysis reported mesh erosion and esophageal stenosis rates of 21% and 25%, respectively, with the increased morbidity being primarily associated with non-absorbable mesh (37). Zhang et al. (15) further showed that mesh reinforcement may reduce short-term recurrence, while biologic mesh was associated with improved short-term quality of life. However, these benefits were offset by a higher incidence of postoperative dysphagia.

Data from recent meta-analyses indicate that mesh reinforcement does not provide significant long-term advantages over primary crural closure alone (38). Reported recurrence rates after mesh-reinforced repair range from 2% to 20% and are closely related to hernia size (39,40). Moreover, recurrence appears to be more frequent than that reported after open surgery (17), while biologic mesh has not been shown to reduce long-term recurrence (41).

These apparently paradoxical findings may reflect the deeper crural bites and more extensive adhesion formation achieved during open repair (10). Alternatively, crural tension may be underestimated during laparoscopic repair, although this hypothesis remains difficult to verify. The adverse effects of tension on suture integrity and hernia recurrence are well established in abdominal wall reconstruction, including inguinal and incisional hernia repair (42). Therefore, although mesh reinforcement is technically safe, convincing evidence that it provides durable protection against hiatal hernia recurrence is still lacking.

After hernia reduction and restoration of normal anatomy, the diaphragmatic crura can be accurately evaluated, often revealing limited suitability for tension-free primary closure (39). Consequently, primary crural repair performed under excessive tension is associated with an increased risk of repair failure. When satisfactory crural reapproximation cannot be achieved without excessive tension, diaphragmatic relaxing incisions become a logical adjunct. From a biomechanical perspective, they should be regarded as tension-releasing maneuvers rather than reconstructive procedures. Although convincing evidence supporting routine mesh reinforcement during hiatal hernia repair remains lacking, reinforcement of the diaphragmatic defect created by a relaxing incision should be considered an integral component of the procedure. In addition, some authors advocate intentional pleural entry to increase diaphragmatic mobility and eliminate restriction caused by pleural adhesions.

After performing a diaphragmatic relaxing incision, the resulting defect is most commonly reinforced with polytetrafluoroethylene (PTFE) mesh, while the hiatal repair is supplemented with absorbable mesh. Clinical experience with this technique remains limited. Greene et al. (17) reported one of the earliest series, including 15 patients who underwent laparoscopic paraesophageal hernia repair with a diaphragmatic relaxing incision to facilitate tension-free crural closure. Right-sided incisions were performed in 13 patients, a left-sided incision in one, and bilateral incisions in one. All patients underwent fundoplication, and both the diaphragmatic defect and the hiatal repair were reinforced with mesh. After a mean follow-up of 15 months, the recurrence rate was 10%, with an overall postoperative complication rate of 27%, consisting mainly of pleural effusion and one pulmonary embolism (17).

Bradley et al. (14) evaluated 33 patients who underwent paraesophageal hernia repair using intraoperative crural tension-relieving maneuvers. These included intentional left pneumothorax in 12 patients, a right-sided diaphragmatic relaxing incision in 15, and a combination of both techniques in 6; no patient underwent a left-sided relaxing incision. All three approaches significantly reduced hiatal tension, leading the authors to conclude that intentional left pneumothorax and/or a right-sided diaphragmatic relaxing incision are effective adjuncts when excessive crural tension is encountered during hiatal repair (14).

Tan et al. (18) retrospectively compared 100 patients with type III paraesophageal hernias who underwent laparoscopic Nissen fundoplication, including 44 who

required a right-sided diaphragmatic relaxing incision and 56 who did not. A biosynthetic mesh was used to reinforce the diaphragmatic defect in 91% of patients undergoing a relaxing incision. Despite significantly larger hiatal hernias in the relaxing-incision group (7.1 vs. 4.9 cm), these patients had lower rates of anatomical recurrence (25% vs. 44%) and symptomatic recurrence (7% vs. 14%), although the differences were not statistically significant. Reoperation rates were similar in both groups. One patient developed gastric perforation secondary to herniation through the relaxing incision and was successfully treated surgically. The authors concluded that right-sided diaphragmatic relaxing incisions should be considered when excessive crural tension is encountered, as they may improve outcomes despite larger hernia size (18).

Taken together, these studies suggest that diaphragmatic relaxing incisions consistently facilitate tension-free crural closure and appear safe, although convincing evidence of a durable reduction in long-term recurrence is still lacking.

Regardless of the perspective adopted, one principle remains clear: the diaphragmatic crura are fundamental to reconstruction of the esophageal hiatus. Their structural integrity should therefore be meticulously preserved during hiatal dissection. Although their intrinsic mechanical properties cannot be modified, minimizing operative trauma and preserving the crural fascia may improve the quality of the repair. In this regard, some authors have combined meticulous fascial preservation with use of the Nathanson liver retractor and reduction of pneumoperitoneum pressure to 8 mmHg, thereby reducing crural tension and facilitating lower-tension repair (34). These technical adjuncts complement diaphragmatic relaxing incisions by optimizing the second essential component of hiatal reconstruction: the quality of crural suturing.

With the same objective, Higashi et al. (33) suggested that laparoscopic anterior gastropexy is a safe and effective option for the treatment of large hiatal hernias, particularly in elderly patients. Furthermore, revisiting several technical adjuncts from the so-called "anatomist era," such as the various forms of gastropexy, may prove beneficial when combined with contemporary surgical techniques without substantially increasing operative complexity. One might speculate that, to design the future of hiatal hernia surgery, it is sometimes necessary to revisit the past. Techniques such as the use of the hernia sac for local reinforcement or different forms of gastropexy, when integrated with modern tension-relieving strategies, may collectively contribute to further improvements in long-term outcomes.

Conclusions

Very large hiatal hernias are increasingly encountered in aging Western populations, and laparoscopic repair can be performed safely and effectively, providing favorable clinical outcomes in most patients. Complete hernia sac dissection and fundoplication are widely accepted as essential components of repair, whereas the roles of esophageal lengthening procedures and mesh reinforcement remain controversial.

Primary crural closure continues to represent an appropriate and widely adopted approach because of its technical simplicity and the extensive clinical experience supporting its use. Although mesh reinforcement remains an important adjunct in selected patients, current evidence has not consistently demonstrated a sufficient reduction in long-term recurrence to justify its routine application.

Diaphragmatic relaxing incisions should be regarded as biomechanical tension-relieving maneuvers rather than reconstructive procedures. Their principal value lies in facilitating secure, tension-free crural closure when primary approximation cannot otherwise be achieved. While they do not appear to substantially reduce long-term recurrence when used in isolation, they represent a valuable adjunct in complex hiatal reconstruction.

There is growing interest in re-evaluating technical concepts previously considered obsolete, including gastropexy and diaphragmatic relaxing incisions. No single adjunctive technique is likely to provide a definitive solution. Rather, future progress in hiatal hernia surgery will probably depend on combining complementary strategies - including tension-relieving incisions, selective mesh reinforcement, preservation of crural tissue quality, and tailored forms of gastropexy - within an individualized reconstructive approach.

General Medical Disclaimer

The information provided herein is for general knowledge and educational purposes only, and should not be taken as professional medical advice. Always consult with a qualified healthcare provider regarding any medical condition or treatment.

Authors' Contributions

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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Institutional Review Board Statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the Sf. Maria Hospital Ethics Committee (approval form no. 12/10 January 2026).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data are available from the corresponding author upon reasonable request.

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