Original Research Article

Characterization of Crural Repair in Antireflux Surgery: Preliminary Experience with a Standardized Technique

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Abstract

Purpose: To define and optimize cruroplasty in laparoscopic repair of hiatal hernia (LRHH).

Background: Crural closure and crural repair in LRHH are used interchangeably. While crural closure entails obliteration of the diaphragmatic defect, cruroplasty involves restoring the anatomy and producing a "functional closure."

Methods: This is an IRB-approved retrospective study. Inclusion criteria were sliding hiatal hernia ≤6 cm in axial length, abnormal pH study or erosive esophagitis, use of the endostitch device to standardize surgical bite, and endoscopic fundoplication to standardize the wrap. Exclusion criteria were a history of antireflux surgery, gastroparesis, or preexisting esophageal stricture.

Results: A total of 68 patients, 21 males, and 47 females met the inclusion criteria. The median age and BMI were 59 and 28, respectively. The average follow-up was 26.3 (12–62) months. There were three anatomical recurrences 3/68 (4.4%) and two of them had symptomatic recurrence. All but eight patients discontinued antisecretory therapy 60/68 (88.2%). Five of these eight patients used these medications at lesser dose or frequency rendering the overall improvement of patients to 65/68 (95.5%). There was no postoperative dysphagia.

Conclusions: Laparoscopic hiatal hernia repair should focus on crural repair, not merely closure. Optimizing cruroplasty can be achieved by understanding the functional anatomy, recreating the crural sling, and adjusting the crural suture tension. This results in a low recurrence rate of hiatal hernias, a high discontinuation rate of proton pump inhibitors, significant objective clinical improvement of GERD symptoms, and no postoperative dysphagia.

Keywords

hiatal hernia, hiatoplasty, cruroplasty, laparoscopic repair of hiatal hernia, gastroesophageal reflux disease

Introduction

The role of the diaphragmatic crura in preventing gastroesophageal reflux disease (GERD) is well established.[1] Dealing with the hiatal defect is an essential component of laparoscopic repair of hiatal hernia (LRHH). "Crural closure" is used interchangeably with "cruroplasty" or "hiatoplasty." However, the difference between these expressions is not just semantics. It is reflected in the techniques used.

Crural closure involves obliteration of the diaphragmatic hiatus via approximation of the ventral borders (anterior aspects) of the crura. This is depicted in Figure 1a, where crural closure can be achieved by approximating the white lines that encircle the esophagus and form a "crural ring." Crural closure revolves around a proper fundoplication which provides the optimal reflux barrier function. Therefore, it aims to protect the fundoplication from intrathoracic migration and recurrence of hiatal hernia.[2] This concept resulted in numerous studies regarding the best fundoplication and the best reinforcement material for robust obliteration of the crural space.[3,4]

Cruroplasty / hiatoplasty aims to meet the same objectives of crural closure by restoring the normal anatomy to form a "functional closure." This can be accomplished by approximating the dorsal borders (posterior aspects) of the crura (green lines in Figure 1), which also approximates the ventral borders (white lines) to recreate the "crural sling." This concept is supported by recent

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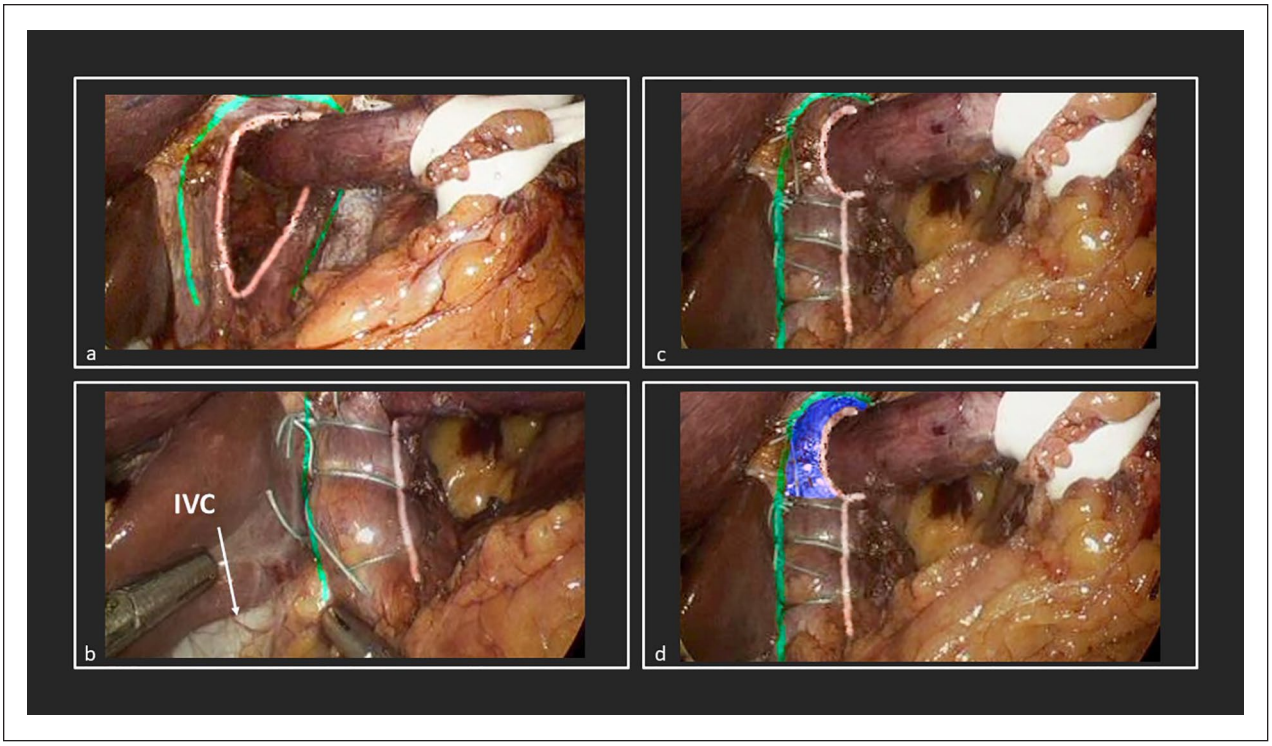

Figure 1. Operative demonstration of the crural sling: (a) initial operative view, the white line represents ventral crural border, and the green line represents dorsal crural border, (b) close up view of the location of the knots, (c) hiatoplasty completed, and (d) crural sling is demonstrated with blue color.

research regarding the significant contribution of the hiatal component of LRHH in GERD control.[5,6]

Postoperative dysphagia is a significant challenge in antireflux surgery. It could be preexisting or de novo, temporary or persisting. There is no consensus in the literature regarding the cause of postoperative dysphagia, whether it is the fundoplication or the crural closure.[5,7] This uncertainty is to be expected in a sophisticated antireflux surgery with two essential operative components and a multitude of operative techniques and variables such as surgical bites, use of mesh, type of fundoplication, division of short gastric vessels, use of bougie, etc. To highlight the impact of the crural sling on postoperative dysphagia in this study, it was imperative to standardize as many variables as possible.

Methods

There are three issues impacting the current operative techniques for the hiatal component of LRHH. First, the limited understanding of the crural sling's complex anatomical and functional aspects. Second, the lack of standardization of the hiatal repair. Third, the inability to gauge the crural tension laparoscopically. This article aims to address these issues.

Our hypothesis is that restoring the normal anatomy and recreating the crural sling result in improvement of GERD symptoms, significant discontinuation of proton pump inhibitors (PPI), low rates of postoperative dysphagia, and hiatal herniation.

This is an IRB-approved retrospective analysis of prospectively collected data for patients who underwent LRHH by a single surgeon between April 2016 and October 2019. Inclusion criteria were age between 20 and 80 years, bothersome GERD symptoms despite use of proton pump inhibitors (PPI) or due to intolerance to PPI, abnormal pH testing (DeMeester score $>$ 14.72) or erosive esophagitis, sliding hiatal hernia 6 cm or less in axial length, follow up for approximately one year or longer, and the use of the endostitch device (Covidien, Mansfield, MA) to standardize the size of the surgical bite. We also included only patients who had LRHH followed by transoral incisionless fundoplication (TIF) to produce nearly identical partial wraps and avoid attributing postoperative dysphagia to the fundoplication. Exclusion criteria were hiatal hernia greater than 6 cm in axial length, esophageal stricture, gastroparesis, Barrett's esophagus longer than 3 cm, or use of mesh, pledgets or any other reinforcement material. We also excluded patients who had laparoscopic fundoplication or previous gastroesophageal surgery.

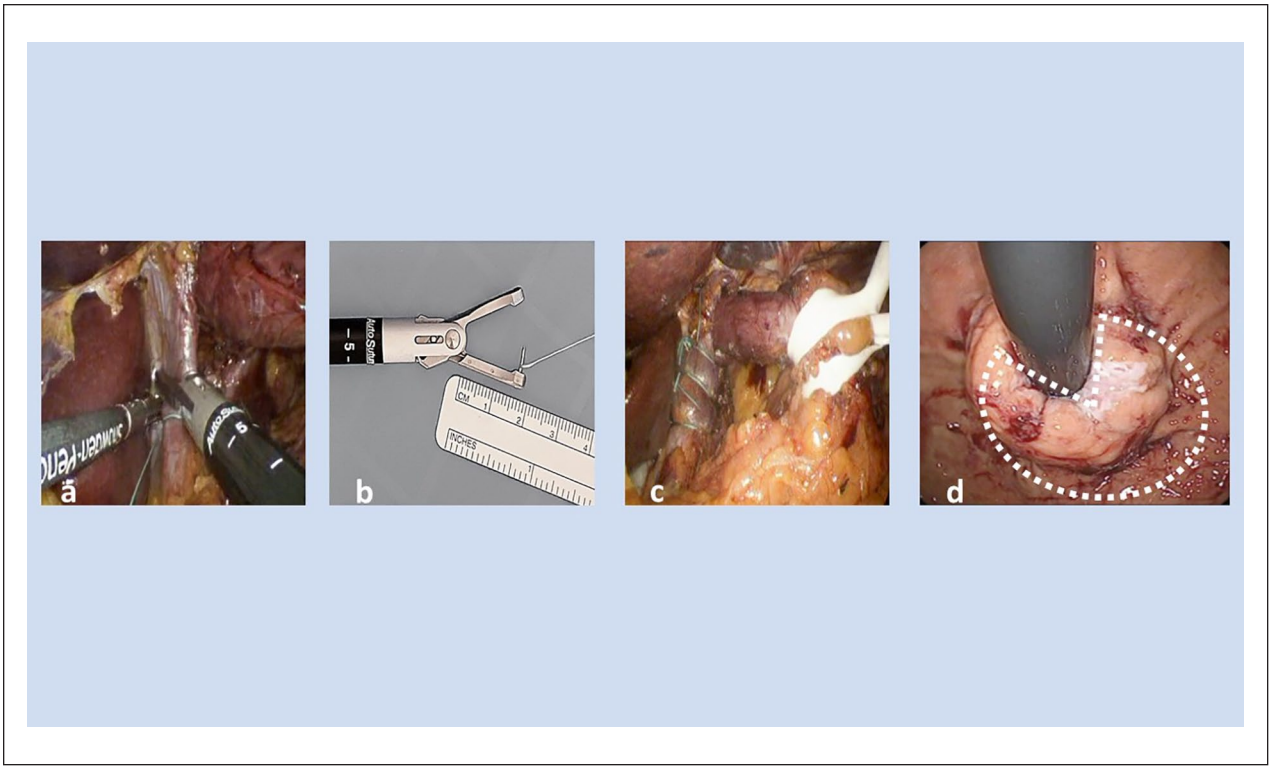

Figure 2. Standardization of crural repair and fundoplication: (a) operative view of the endostitch device, (b) the size of the crural surgical bite about 1.7 cm, (c) the posterolateral location of the ESAK, and (d) a 270° TIF valve.

Diagnostic Workup

All patients had upper gastrointestinal imaging (UGI), esophagogastroduodenoscopy (EGD), and 48 hour pH testing. High resolution impedance manometry (HRIM) was selectively used at our facility for dysphagia or abnormal findings on UGI. Patients who had HRIM at outside hospitals were also included. We utilized GERD-Health Related Quality of Life (GERD-HRQL), Heartburn Score, Regurgitation Score and Reflux Symptom Index (RSI) while patients were on antisecretory therapy.

Disease-Related Quality of Life Measures

This study used validated, disease-specific questionnaires to assess GERD symptoms, GERD-HRQL and RSI.[8,9] The GERD-HRQL questionnaire is a disease-specific questionnaire validated to measure the severity of GERD symptoms. It consists of 16 questions that specifically address typical GERD symptoms. Each question has a score ranging from 0 to 5, and the best possible aggregate score is 0 (asymptomatic), and the worst score is 80 (severe symptoms). A total score $\geq$15 is considered abnormal. The dysphagia subscore ranges between 0 and 5. The heartburn score and the regurgitation scores are subscores of GERD-HRQL. Both range from 0 to 30. The heartburn score is the sum of the first 6 questions, while the regurgitation score is the sum of the last 6 questions.

RSI is a 9-item evaluation instrument that was developed to measure atypical GERD symptoms. Each item score can range from 0 (asymptomatic) to 5 (severe symptoms) with a maximum total score of 45. A total RSI score of $\leq$13 is considered normal, whereas patients with a total RSI score $>$19 are considered likely to have laryngopharyngeal reflux (LPR).

In this study, the primary effectiveness endpoint was defined as the elimination of daily bothersome typical or atypical symptoms (scores $\leq$2 on each question on the GERD-HRQL and RSI) or clinically significant improvement (defined as $\geq$50% reduction in total GERD-HRQL and RSI).

Patient satisfaction with current health condition was assessed as part of the GERD-HRQL questionnaire and was recorded as "satisfied," "neutral," or "dissatisfied.

Operative Details

The diaphragmatic hiatus was repaired with permanent sutures using the endostitch device with a standardized hiatal bite of approximately 17 mm (Figure 2a and b). We utilized the extracorporeal sliding arthroscopic knots (ESAK) which are formed extracorporeally and advanced

with a knot pusher (see Video, Supplemental Digital Content 1, which demonstrates the use of ESAK knots). These are cinching knots similar to the knots used in the Endoloop Ligature (ETHICON; Bridgewater, NJ, USA). They are precisely placed between the posterolateral aspect of the right crus and inferior vena cava (IVC) (Figures 1b and 2c). In this location, they approximate the ventral as well as the dorsal borders of the crura. This results in an apposition of the diaphragmatic crura's entire width, which is called diaphragmatic eversion.[10] We left long sutures tails to allow further cinching using a side knot pusher.[11] Bougie was not utilized. TIF was performed for the antireflux component to create a 270 degrees wrap using the EsophyX device (Figure 2d).

Follow Up

We utilized the same preoperative GERD questionnaires, UGI, and EGD. Postoperative dysphagia was noted if it required endoscopic dilatation or when marked as >2 out of 5 on GERD-HRQL "difficulty swallowing" item. UGI was performed annually or longer when patients presented for follow up. Radiological recurrence was defined as a hiatal hernia ≥2 cm in axial length. Endoscopic follow up was performed for patients requiring surveillance for Barrett's esophagus or for any other indications. A recurrence was considered present if the gastroesophageal junction was found to be proximal to the crural impressions on either anterograde or retroflexion endoscopic view.

Results

A total of 68 patients, 21 males, and 47 females met the inclusion criteria. The median age (years) and BMI (kg/m^2) were 59 and 28, respectively. Patients had troublesome GERD symptoms for a median of 15 years and 94.1% of them used PPI for a median of 10 years. The rest of the demographics, preoperative diagnostic workup, and operative findings are listed in Table 1.

The average follow up was 26.3 (12-62) months. There were three anatomical recurrences, 3/68 (4.4%), and two of them had symptomatic recurrence. One of these three patients with anatomical recurrences had a massive caudate lobe which was as large as the left lobe of the liver. This condition was not previously reported in the literature and was later published as a case report.[11] The operative field was extremely limited which was slightly improved with the placement of another laparoscopic liver retractor. The second patient had a preoperative diagnosis of erosive esophagitis C. On table endoscopy showed esophagitis D. Mediastinal dissection was challenging and while we believed that intraabdominal length of esophagus was adequate, in retrospect, it was not sufficient. This

Table 1. Characteristics of the Study Population.

Demographics	
(Median & IQR)	
Age (years)	59.0 (15.3)
Gender F/M	47/21
BMI	28.0 (6.3)
GERD duration (years)	15 (19)
Proton pump inhibitors use	
N	64 (94.1%)
(years)	10 (18.5)
Preoperative data	
EGD	
Hiatal hernia axial height (cm)	
<3	26/68
3–5	38/68
>5	4/68
Erosive esophagitis (*N* = 55)	
A	37/68
B	11/68
C	7/68
Hill's Grade (*N* = 64)	
II	54/68
III	8/68
IV	2/68
DeMeester score (*N* = 59)	
(Median & IQR)	
Composite score	28.5 (19.6)
Day 1 score	19.9 (21.7)
Day 2 score	24.3 (22.8)
Operative data	
(Mean & SD)	
ASA	2.4 ± 0.6
Duration of the entire operation (minutes)	123.9 ± 25.9
Duration of hiatoplasty (minutes)	11.1 ± 3.4
Duration of TIF (minutes)	32 ± 8.4
Aberrant left hepatic artery	10/68
Length of stay (days)	1.2 ± 0.6
GERD Questionnaires	
Follow up (months – Median & IQR)	24.0 (24.3)
Preoperative versus postoperative, P value	
GERD-Health Related Quality of Life (HRQL)	33.9 ± 15.1 versus 5.7 ± 9.4, <0.0001
Dysphagia subscore > 2	19/68 versus 0/68, <0.0001
Regurgitation subscore ≥10	50/68 versus 4/68, <0.0001
Heartburn subscore ≥10	50/68 versus 5/68, <0.0001
Reflux Symptom Index (RSI)	15.2 ± 11.3 versus 5.9 ± 5.5, <0.0001
Health satisfaction survey	
Satisfied	2/68 versus 61/68
Neutral	12/68 versus 2/68
Dissatisfied	54/68 versus 5/68
Follow up studies	
Follow up (months – Median & IQR)	24.5 (24.8)
UGI	46/68
EGD	22/68
Postoperative dilation	0/68
Anatomical hiatal hernia recurrence	3/68
Massive caudate lobe	1/3
Erosive esophagitis D	1/3
Discontinuation of antisecretory medications	60/68
Less frequent use than preoperative	5/68

Note. Data expressed as means and standard deviations (SD) for normally distributed data and as median with interquartile range (IQR) for non-normally distributed data.

was compounded with heavy lifting a few weeks postoperatively due to financial reasons. There was no postoperative dysphagia compared to the preoperative dysphagia rate of 19/68 (27.9%). All but eight patients discontinued antisecretory therapy 60/68 (88.2%). Five of these eight patients used these medications at lesser dose or frequency, rendering patients' overall improvement to 65/68 (95.5%). The statistically significant reduction of preoperative GERD scores and the increase in patient satisfaction postoperatively is shown in Table 1.

Discussion

Understanding the causes of the increased symptomatic, anatomical recurrence rate and dysphagia following LRHH is a complex task. This is due to multiple technical variables among foregut surgeons. For example, the type of fundoplication (complete vs partial), the size of surgical bite (large vs small), and the use of reinforcement material (primary repair vs mesh or pledgets).[4,12,13]

This study addresses these variables by creating an almost identical partial fundoplication (TIF) to focus on hiatal repair, which is not standardized and is often cited as a cause of the high recurrence rate associated with LRHH.[14] We standardized the size of the surgical bite (the endostitch device) and the location of the knots placed by a single surgeon to perform primary, non-reinforced repair of the diaphragmatic hiatus (Figure 2).

Proper repair aims to restore the crura's anatomical morphology and physiological function. There are three issues hindering the performance of optimal cruroplasty. Limited understanding of the crural sling, lack of operative standardization, and inability to gauge and adjust hiatal tension.

Understanding the Crural Sling

The esophageal hiatus is made by the medial and lateral bundles of the right crus. It is customary to refer to the medial bundle as the right crus and the lateral bundle as the left crus. We will use the surgical, not the anatomical, description for this discussion.

Computed modeling, manometric and CT imaging enhanced the understanding of the functional morphology of the crura.[15,16] The diaphragmatic hiatus is placed obliquely across the esophagus. As the esophagus bends to the left at the upper aspect of the hiatus, the hiatus and the esophagus are placed at a right angle to each other. This angulation is helped by the movement of the mobile left crus to the immobile right crus during crural contraction. The entire width of both crura is applied to the esophagus to generate circumferential pressure on the gastroesophageal junction. This is the basis of the crural sling.

To surgically recreate this anatomy, the entire width of the crura should be in good apposition. When the hiatoplasty knots are placed on the ventral border of the crus (white lines in Figure 1a), they approximate this portion of the crus and separate the dorsal counterparts (green lines in Figure 1a). This results in triangular cross section and crural inversion (Figure 3b and f). In contrast, when the hiatoplasty knots are placed posterolaterally (Figure 1b), they approximate the entire width of the crura and result in a rectangular cross section and crural eversion (Figure 3a and e). This good apposition is demonstrated in preoperative and postoperative coronal CT images (Figure 4).

Thoracic surgeons made a significant contribution to our understanding of the crural sling. This concept was first established in the mid-twentieth century by British surgeon Phillip Allison who focused on transthoracic restoration of the crural sling, which enables the crural fibers to function as a pinchcock.[17]

Thoracic repair of hiatal hernia was shown to have a lower hiatal hernia recurrence rate than LRHH.[18] This could be due to better esophageal mobilization or improved esophageal length and tension assessment. Yet, it could also be due to a superior repair of the hiatus. This is appreciated by referring to Figure 1a, where the thoracic approach can easily approximate the green lines facilitating the recreation of crural sling (Figure 2c). In the laparoscopic era, the current teaching is to preserve the peritoneal covering of the anterior edge of the crus to hold the sutures. This leads to an approximation of the ventral borders only and forms a "crural ring" around the esophagus (Figure 2d).

To overcome this laparoscopic challenge, the knots are placed between the posterolateral aspect of the right crus and IVC.[19] This is the area where a right relaxing diaphragmatic incision is usually made (Figure 1b). There is always a peritoneal covering to hold the knots in this location. Securing the knots in this position leads to crural eversion and recreation of the "crural sling." However, placing the knots in this location is not straightforward using the current suturing techniques. The extracorporeal arthroscopic knots (ESAK) can precisely place these knots in this location (see Video, Supplemental Digital Content 1, which demonstrates the precise placement of crural stitches). These knots are used mainly by arthroscopic surgeons in tight joint spaces where intracorporeal stitching is not feasible. They do not unravel, can navigate anatomical barriers, and require the single utilization of a knot pusher.[11]

Standardizing Cruroplasty

There is no current standardized technique for LRHH, and suboptimal cruroplasty is the most common cause of

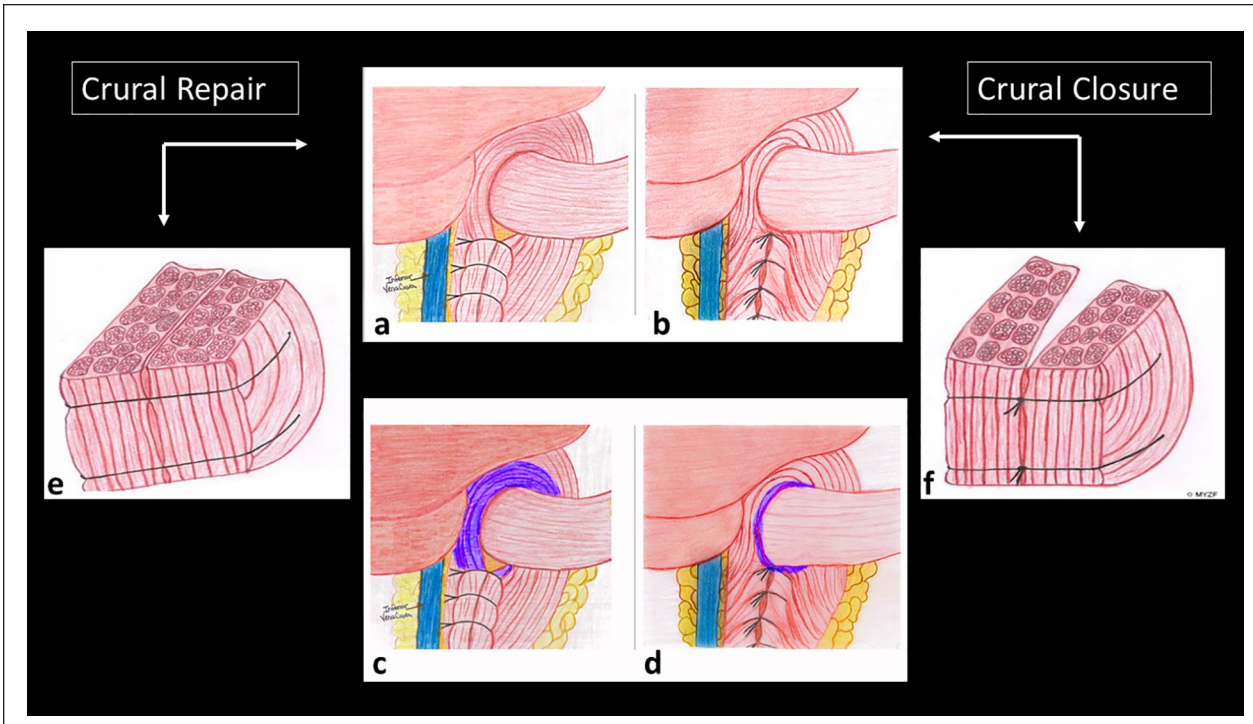

Figure 3. Crural repair versus crural closure: (a) crural Eversion with the posterolateral placement of the knots, (b) crural closure with the anterior placement of the knot, (c) enhanced picture showing crural sling, (d) enhanced image showing crural ring, (e) cross-section of cruroplasty, and (f) cross-section of crural closure.

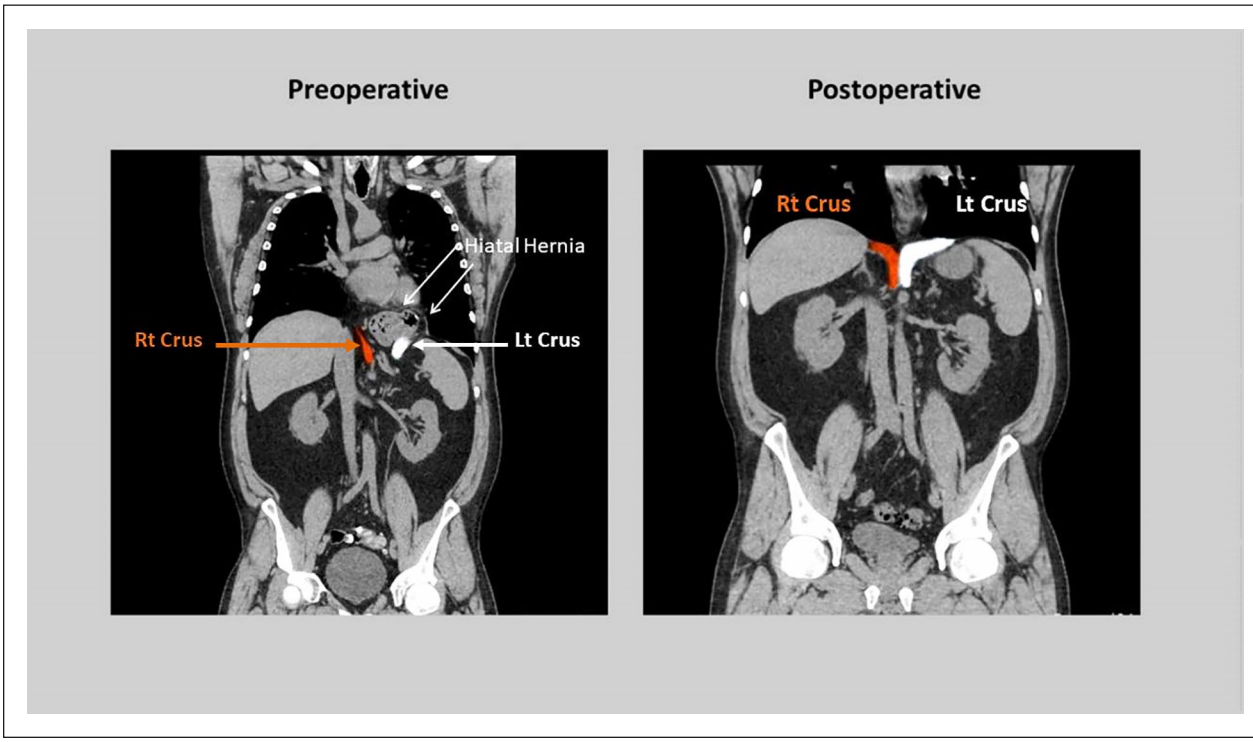

Figure 4. Preoperative and postoperative coronal CT images demonstrating apposition of both crura.

hiatal hernia recurrence.[14] While eliminating all technical variables is impossible, we endeavored to standardize the following four variables.

First, this study focused solely on the primary repair. *Second*, the surgical crural bite was standardized using the endostitch device. *Third*, the location of the knots against the ever-present peritoneal covering of the posterolateral aspect of the right crus and the method of tying the knots (ESAK) were consistent. *Fourth*, we utilized TIF to create a nearly identical partial endoscopic fundoplication that does not require fixation of the wrap to the crura, which is common practice in laparoscopic fundoplication. This eliminates any impact of the fundopexy stitches on the integrity of the crural repair.[10] Moreover, the TIF partial fundoplication is important as it avoids attributing postoperative dysphagia to the wrap.

Gauging and Adjusting the Crural Tensions

One of the main difficulties in laparoscopic cruroplasty is appreciating the crural tension. Inappropriate estimation of the tension can lead to either crural tear or loose stitches. Several methods were reported to measure the crural tension.[20,21] However, the static measurement of the crural tension is insufficient for the dynamic hiatal repair as the shape of the hiatus and the crural tension change with the placement of subsequent stitches. Surgeons endeavor to ensure that the crural repair is not too tight or too loose. This is challenging as they cannot predict the impact of the successive sutures on the previous ones.[19] A common operative scenario is shown in Supplemental Digital Content 1. After the placement of three crural stitches, the second stitch became loose. There are two options to entertain. The first option is to accept that the tension is uneven, which is not technically proper. The second option is to remove the second stitch and redo it. However, the hiatus is partially closed, and the impact of the new second stitch on the tension of the other stitches is unknown. We utilized a third option which was the use of ESAK to cinch the second knot further. This led to the loosening of the third stitch, which was further cinched.

This current study shows that cruroplasty and restoration of the crural sling mechanism result in no postoperative dysphagia, a high rate of discontinuation or reduced use of long-term PPI therapy, and low recurrence of hiatal hernia. The difference between preoperative and postoperative GERD scores was statistically significant in all questionnaires.

Limitations

This study is limited by the inherent drawbacks of retrospective studies performed by a single surgeon. It has a relatively short follow up and a high percentage of patients with low grade esophagitis. Prospective studies with longer follow up are needed to validate this technique.

Conclusion

Laparoscopic hiatal hernia repair should focus on crural repair, not merely closure. Optimizing cruroplasty can be achieved by understanding the functional anatomy, recreating the crural sling, and adjusting the crural suture tension. This results in a low recurrence rate of hiatal hernias, a high discontinuation rate of proton pump inhibitors, significant objective clinical improvement of GERD symptoms, and no postoperative dysphagia.

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Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

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