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LAPAROSCOPIC SURGERY

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Contributors

Francisco Miguel Sánchez-Margallo, Juan A. Sánchez Margallo, Javier Hermoso De Mendoza, David Zimmerman, Stefan Clermonts, Laurents Stassen, Thomas Lango, Erlend Hofstad, Ronald Mårvik, Chih-Kun Huang, Prasad Madhusudan Bhukebag, Sir Emmanuel Astudillo, Khan Wei Chan, Alessandro M. Paganini, Andrea Balla, Silvia Quaresima, Ardit Seitaj, Andrea Isidori, Franco Iafrate, Arshad Malik

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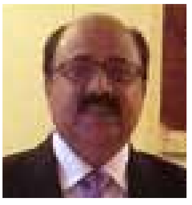

Dr. Arshad M. Malik is an associate professor of Surgery at the College of Medicine, Department of Surgery, Qassim University, Saudi Arabia. He developed special interest in laparoscopic surgery and then got training in India and Singapore, to name a few. Presently he is an assistant editor of the *International Journal of Health Sciences* which is an official journal of Qassim University. He is a reviewer of the *British Journal of Medical Practitioners* as well as many other international journals. He is the author of 46 national and international scientific papers which are well appreciated in the health community. He is the editor of one book on *Advances in Laparoscopic Surgery* wherein he has contributed one chapter on the laparoscopic appendectomy. His chapter on "The Recent Trends in the Management of Appendicular Mass" has attracted a massive readership and has been downloaded for 17,000 times all over the world. He has been presenting his work on the floor of many well-established and renowned surgical and laparoscopic societies like ELSA, SLS, APHS, WCES, IAGES, EAES, EHS, and AHS in India, Italy, Spain, New York, Los Angeles, Yokohama, Belgium, Indonesia, Singapore, Vietnam, etc., to name a few. His work has been appreciated and well taken by the experts in this field.

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Preface

The present era has seen a revolution in the field of surgery where there has been a dramatic shift from the traditional open surgery to minimal access surgery. This change is not an overnight phenomenon but a result of vision, hard work, and dedication of many individuals over the past few decades. The early pioneers planted the seeds which, with a continuum of the same struggle by the present experts in this field, have expanded to and have become a huge tree of the modern present-day laparoscopy with many branches emerging every day.

We can still find patients, operated before the dawn of laparoscopic era, carrying big incisions on the operative sites. At the outset, most of the surgeons who were trained for open surgery were very reluctant and did not show eagerness to learn this technique. Soon it was realized that the laparoscopic surgery will not gain widespread acceptance unless the training of this technique is offered to surgeons all over the world. At that time, there was a dearth of properly trained medical and paramedical personnel, and there were very few properly qualified and trained surgeons who took this as a challenge to bring a phenomenal change to improve the outlook of surgical patients. It did not take very long when we saw surgeons developing an unfailing interest in learning and practicing this technique. I remember very clearly when I started the minimal access surgery, there were hardly few operations performed like cholecystectomy, appendectomy, etc. On the contrary, there was a long list of contraindications to laparoscopic surgery. This is attributed to lack of well-trained manpower as well as lack of properly trained paramedical staff and lack of recognized training programs and also the learning curve of this technique. Now as evident from studies from all over the world, there seems to be virtually no contraindications to the laparoscopic procedures, and almost every procedure is being performed through this technique.

Initially, the procedure gained popularity as it was associated with less pain, short hospital stay, and rapid recovery. The initial basic principles of the basic procedures were well taken and got established very early and at a very fast pace. Later on, all the energy was focused on the various advance procedures which were not performed as commonly as the basic laparoscopic procedures like cholecystectomy and appendectomy. Later on, the cosmetic gain of this technique attracted a worldwide popularity and people started working on this aspect. This led to the emergence of various advancements in this technique to make it more and more sophisticated in terms of cosmetic results and improvement in the operating techniques. Now people are more in the practice of scarless surgery, whereby patients have no obvious scar on the body. This target is being achieved by SILS, natural orifice transluminal endoscopic surgery (NOTES), etc. which is now gaining worldwide popularity. Robotic surgery is a further advancement in this field gaining global acceptance, and a large number of centers are performing robotic surgery as a routine.

This book is just a step forward for the readers to learn further the diagnostic and therapeutic value of this novel technique. I hope that it will be a great help for the junior laparoscopic surgeons as well as it will attract attention of those who are routinely performing the laparoscopic surgery.

Any positive criticisms/suggestions are more than welcome.

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Chapter 1

The Evolution of Minimally Invasive Techniques in Restoration of Colonic Continuity

Stefan H.E.M. Clermonts, Laurents P.S. Stassen and
David D.E. Zimmerman

Additional information is available at the end of the chapter

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Abstract

Restoration of bowel continuity after Hartmann's procedure is considered technically challenging and is associated with high morbidity and mortality. This is the main reason why restoration of intestinal continuity is often not attempted. Over the past decade, considerable international experience has gained on this topic with new minimally invasive techniques being developed. This review details the evolution of minimally invasive techniques in restoration of colonic continuity after Hartmann's procedure. A comprehensive search of PubMed and Embase was done. Different restoration modalities were included. Eight studies, from six different countries, in which multiport laparoscopic restoration of continuity was compared to conventional open restoration of bowel continuity, were included. In the total of 254 patients, continuity was restored laparoscopically compared with 255 patients in which continuity was performed in open fashion. Restoration of bowel continuity via trephine access was also reported; three studies including 37 patients were included in this review. Single-port restoration of bowel continuity after Hartmann's procedure is a natural evolution of multiport laparoscopy and trephine access. Six studies reporting on single-port reversal of Hartmann's procedure were included with a total of 75 patients. Single-port access in combination with a transanal approach has also been reported; however, data are extremely limited as there is only one study in the published literature. Success of restoration of bowel continuity with less morbidity and mortality has been demonstrated throughout the evolution of the different surgical techniques. In this review advantages of different approaches for restoration of bowel continuity after Hartmann's procedure are discussed. Furthermore, surgical techniques are described, pictorial guides are added for some techniques, and flowcharts are given for easy use during clinical decision-making.

Keywords: Hartmann's procedure, restoration, intestinal continuity, surgical techniques, laparoscopic, minimal invasive, single-port laparoscopy

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1. Introduction

In this chapter we would like to focus on the restoration of intestinal continuity after Hartmann's procedure in general and highlight emerging minimally invasive techniques in specific.

Historically, restoration of bowel continuity after Hartmann's procedure has been considered technically challenging and is associated with high morbidity and mortality rates even despite modern surgical techniques. This is the main reason why restoration of intestinal continuity is often not attempted. Intraoperative difficulties during laparotomy or multi-port laparoscopy are mainly caused by the formation of adhesions at the laparotomy site and lower part of the abdomen after active inflammation and/or infection and previous surgery.

The use of the former colostomy site as access to the abdominal cavity has gained some popularity recently. Placing a single-port access system in the former colostomy site combines the potential benefits of minimally invasive surgery (shorter postoperative recovery time, minimal postoperative hospital stay, and lower morbidity rates) with the advantages of Hartmann's reversal through the colostomy site (the absence of new incisions and decreased necessity of midline adhesiolysis).

2. Hartmann's procedure: historical perspective

Henri Albert Hartmann was born on June 16, 1860. Hartmann finished his medical school at the University of Paris on December 19, 1881.

Hartmann starts his internship with Felix Terrier at Hôpital Bichat, who was considered to be one of the most authoritative surgeons at that time [1]. After finishing his surgical training in 1887, Hartmann was appointed as an assistant professor in 1895 and in 1909 as a professor and chairman of the Department of Surgery in 1892. In 1914, Hartman became the chief of Surgery at l'Hôtel-Dieu hospital in Paris (**Figure 1**) [2]. During his lengthy and extraordinary career, Hartmann meticulously recorded each operation he performed. Upon his retirement he had documented around 30,000 cases [3].

Hartmann's procedure was first described in 1921 [4, 5]. In his first patients with obstructive carcinoma of the sigmoid, he performed a proximal colostomy and then a sigmoid resection with closure of the rectal stump via an abdominal approach. He developed this technique in response to high mortality rates in his patients who underwent an abdominoperineal resection, as first described by Miles in 1908 [1]. In 1931 Hartmann described the procedure in detail in his book *Chirurgie du Rectum* (**Figure 2**).

Although Hartmann developed his technique mainly for rectal cancer, in present times, Hartmann's procedure is often the preferred procedure for severe diverticulitis of the sigmoid. Despite Hartmann never intended restoration of bowel continuity, recent publications showed that a direct reconstruction is feasible in selected patients [6].

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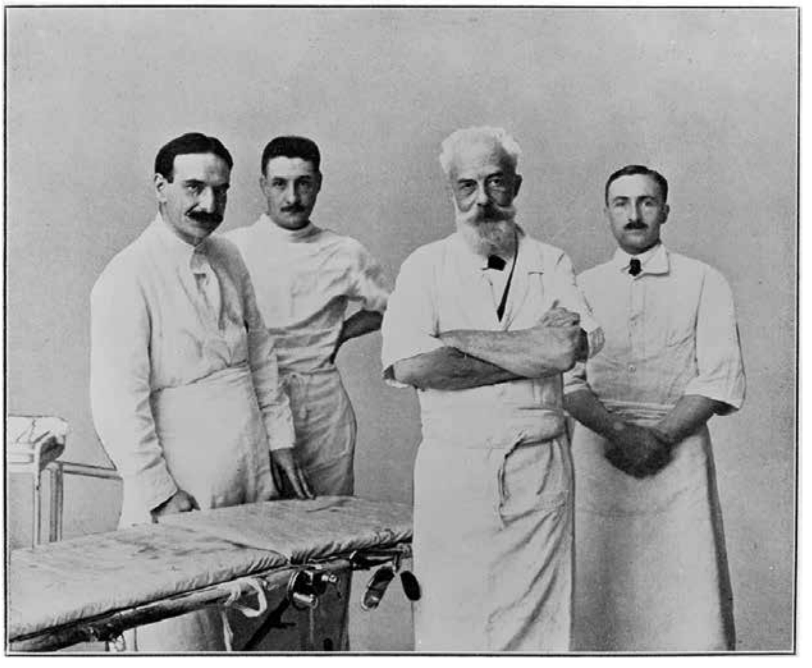

Figure 1. Henri Hartmann (second from the right) and his three assistants, Drs. Bergeret, Gouverneur, and Huet, at the Hotel-Dieu, Paris. Source image: http://wellcomeimages.org.

2.1. Reversal of Hartmann's procedure

Hartmann never attempted to reanastomose the bowel in his patients. He believed this would result in unnecessarily high morbidity and mortality [3].

Restoring intestinal continuity after Hartmann's operation is a difficult operation that is associated with a high morbidity rate, with anastomotic leakage rates ranging from 4% to 16% and an operative mortality reported as high as 10% [7–10].

The high incidence of morbidity and mortality is the main reasons why surgeons are reluctant to restore intestinal continuity in approximately 40% of the patients undergoing Hartmann's procedure [10, 11].

2.2. Indications and contraindications

The primary indication for reversal of Hartmann's procedure is curing people of the discomforts that are caused by the end colostomy. Patients with stomas face many physical and psychological challenges, including leakage, skin rashes, lifestyle alterations, and sexual dysfunction [12, 13].

Literature defines no contraindications for reversal of Hartmann's procedure. However, a review of the literature covering restoration after Hartmann's procedure shows that advanced age, ASA grade 3, or higher and fecal peritonitis at the time of Hartmann's procedure are

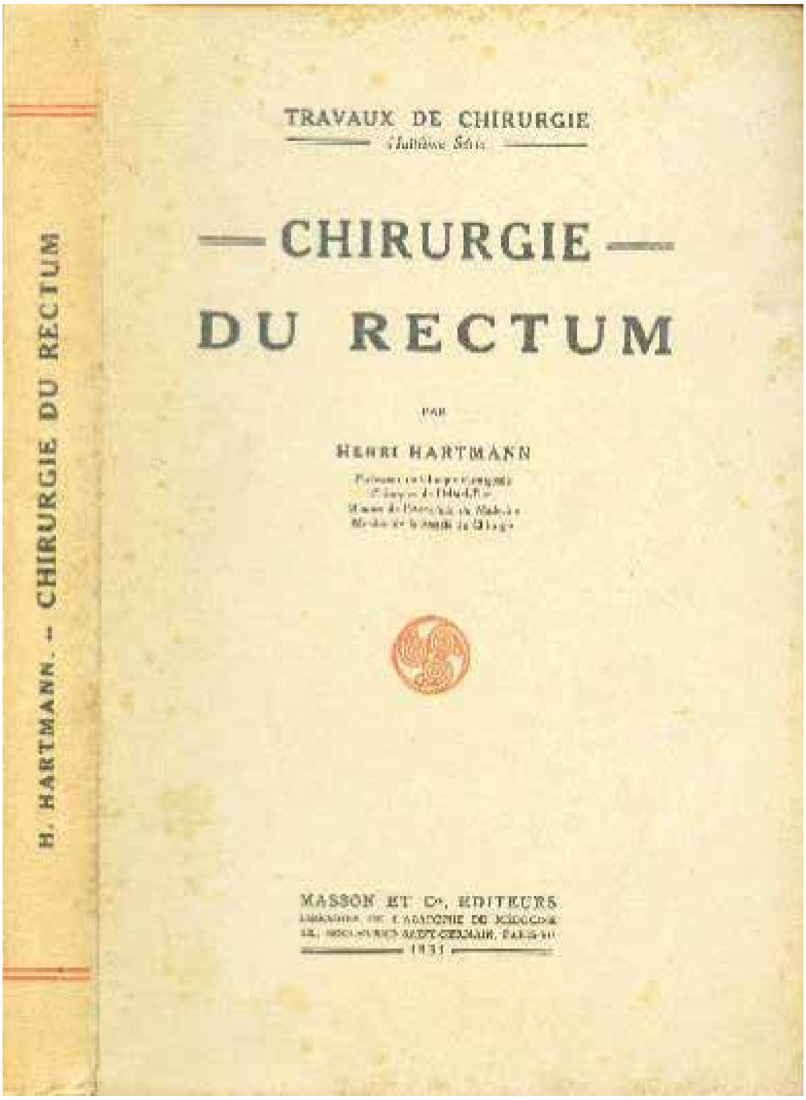

Figure 2. Cover of the book *Chirurgie du rectum* by Henri Hartmann. Published 1931. Source image: http://archive.org.

often considered relevant contraindications. Roque-Castellano and colleagues analyzed factors related to the decision of restoring intestinal continuity. They found that female sex and neoplastic disorders are relative contraindications for restoration of intestinal continuity [14]. Furthermore, we believe there must be some reluctance to perform conventional restoration of bowel continuity by laparotomy in patients with an incisional hernia. The reason for this statement is the need for repair of the incisional hernia and the restoration of the bowel continuity at the same time. This reluctance is following the dictum that abdominal wall prostheses must be avoided during contaminated operations [15]. The authors advocate

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the use of single-port laparoscopic reversal of Hartmann's procedure in case of an incisional hernia. With this modality the midline can be left unchanged rendering concomitant repair of the incisional hernia unnecessary. The single-port laparoscopic technique will be discussed in detail in Section 5.1.

2.3. Preoperative workup

Prior to the restoration of the intestinal continuity, routine evaluation of the rectal stump and descending colon is often performed in order to detect stump leakage, cavity formation, or strictures and establish the length of the rectal stump. The integrity and patency of the rectal stump are evaluated by physical examination, flexible endoscopy and/or radiographically by contrast proctography CT scan. Despite these routine practices, little data exist to support this in case of restoration of bowel continuity after Hartmann's procedure. Data do exist on the routine use of contrast enema prior to the closure of a defunctioning ileostomy in patients with low pelvic anastomosis is inconsistent when its sole purpose is detecting leaks or cavity formation [16–18]. These studies show that strictures or narrowing of the bowel lumen is seldom detected. In cases where strictures are detected, dilatation is performed without the need for cancelation the reversal of the – ostomy. When extrapolating these findings, it is questionable whether routine contrast studies are necessary in the case of Hartmann's reversal. Moreover, usually patients who develop an anastomotic leak of the rectal stump present with clinical symptoms long before restoration of the bowel continuity is scheduled. However, in patients where initial Hartmann's procedure was acutely performed for neoplastic disorders, direct visualization of the rectal stump and remaining colon is mandatory to exclude recurrence of the malignancy or other neoplastic lesions. Based on these limited data, the authors advocate performing flexible rectoscopy to ensure viability of the rectal stump and the absence of remaining diverticular disease or local recurrence in case of prior malignancy. Data on routinely performing X-ray or contrast enema is limited to expert opinions and therefore not mandatory. Authors' recommendations are summarized in the algorithm in **Figure 3**.

2.4. Timing of surgery

There is limited data available concerning the optimal timing of restoration of continuity. Most surgeons will postpone surgery for at least 6 months after the initial operation, obviously depending on the current health and recuperation of the patient. It has been suggested by Keck and coworkers that a waiting period of 15 weeks may be beneficial [19]. It is however noteworthy that reversing Hartmann's procedure after a shorter period did not influence morbidity or mortality, but did seem to lengthen the duration of hospitalisation and increase the perceived operative difficulty (and thus the risk). Other authors have also suggested there is no indication to delay closure for longer than 16 weeks [20]. Based on these limited data, the authors advocate a minimal waiting period of 4 months between the initial operation and restoration of continuity in order to maximize the possibility of minimally invasive techniques for restoring continuity.

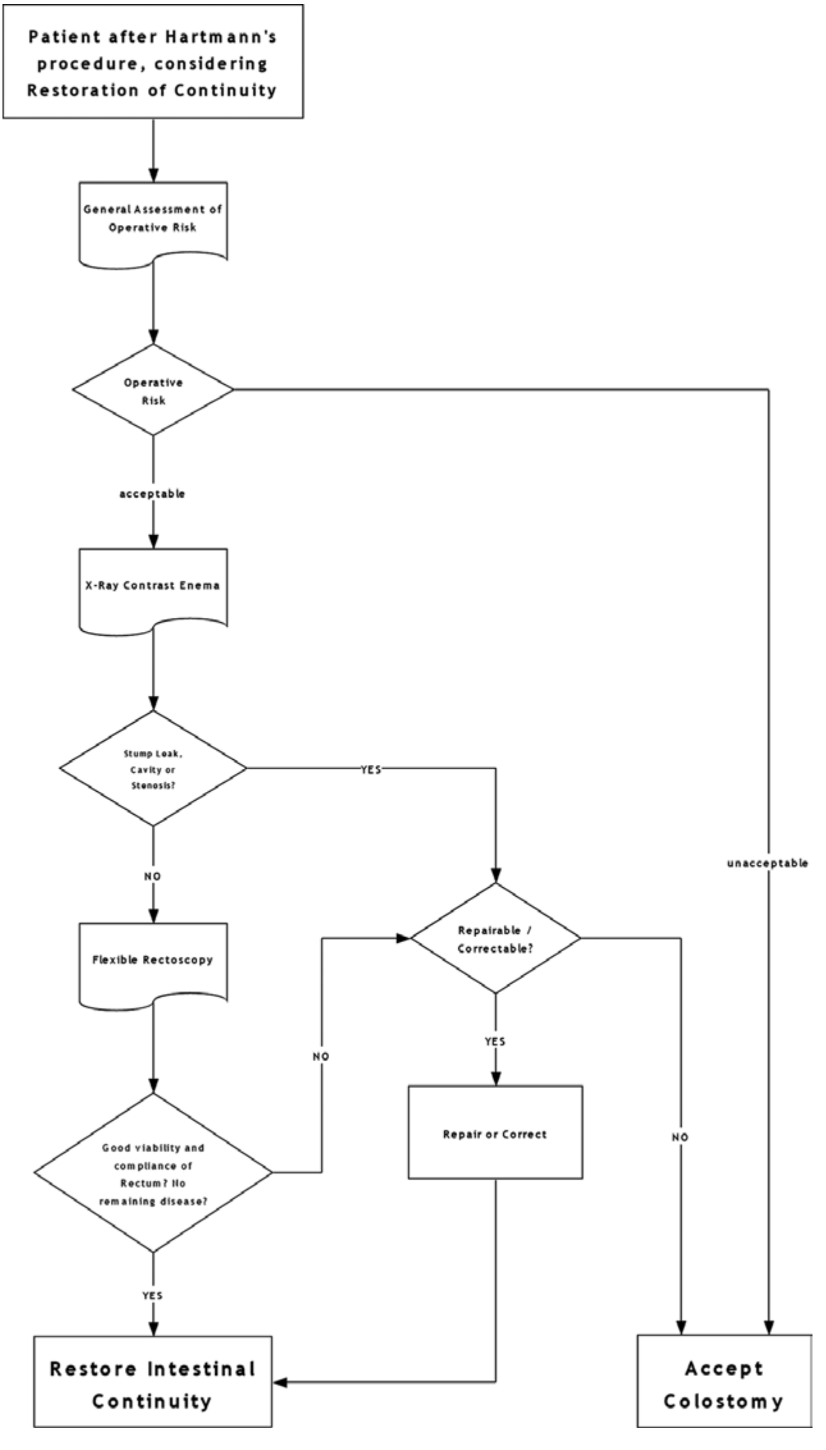

Figure 3. Algorithm advocated to be used during decision-making and the preoperative workup for restoration of bowel continuity after Hartmann's procedure.

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3. Surgical techniques for restoration of intestinal continuity after Hartmann's procedure

Reestablishing bowel continuity after Hartmann's procedure is considered a major surgical procedure that is accompanied by considerable morbidity and mortality. Multiport laparoscopy was the first technique in a sequence of attempts to reduce the high morbidity and mortality that is associated with this procedure.

3.1. Multiport laparoscopic reversal of Hartmann's procedure

The patient is placed in a supine position. Next, there are two different ways to continue the procedure. In one option the procedure is initiated with mobilization of the stoma to the level of the abdominal wall and then freeing the ostomy from the fascia. The alternative procedure starts by insertion of a 10 mm camera trocar and a working trocar when needed (**Figure 4**), establishing the pneumoperitoneum, and perform a prior inspection for factors that could potentially cause abortion later on in the procedure. We advocate starting the procedure in the latter fashion, since this technique facilitates early decision-making by the surgeon on continuing or aborting the procedure when a potential unsuccessful bowel restoration is anticipated. Consequently, there is no need for refashioning of the end colostomy.

In both techniques the next step is transecting the colon using a linear stapler to remove the end of the colostomy and securing the anvil of a circular stapler is secured with a purse-string suture, in the proximal colon. The descending colon is then returned into the abdominal cavity. Any adhesions in the abdominal cavity are freed to enable insertion of the other ports. The colostomy site is closed using a wound protector/retractor device with a laparoscopic cap so that it can function as an additional working port. The pneumoperitoneum is then established. Additional 5 mm working trocars are placed in the right upper quadrant and right iliac fossa. Extensive dissection of adhesions from the anterior abdominal wall in the midline is mandatory with this multi-port technique in order to cross the midline (**Figure 4**).

The small bowel is mobilized from the left iliac fossa and out of the pelvis. The proximal descending colon would have been mobilized to a varying extent at the initial Hartmann's procedure, and this will need to be redone, including the splenic flexure. A rectal probe or circular stapler sizer is used to identify the rectal stump. In order to perform an end-to-end anastomosis, further mobilization and adhesiolysis of the rectal stump are sometimes necessary. Alternatively, if mobilization is difficult and the anterior rectal wall can clearly be identified and adequate length of the descending colon is available to allow a tension-free anastomosis, an side-to-side anastomosis can be performed. A circular stapler is introduced into the rectum to fashion the anastomosis. The stapler is deployed and the donuts are checked. Next, we advocate performing an additional leak test as this is associated with reduced rates of postoperative adverse events in literature [21]. The pneumoperitoneum is released, and the trocars are removed under direct visualization. The fascia is then closed in apertures equal to or larger than 10 mm.

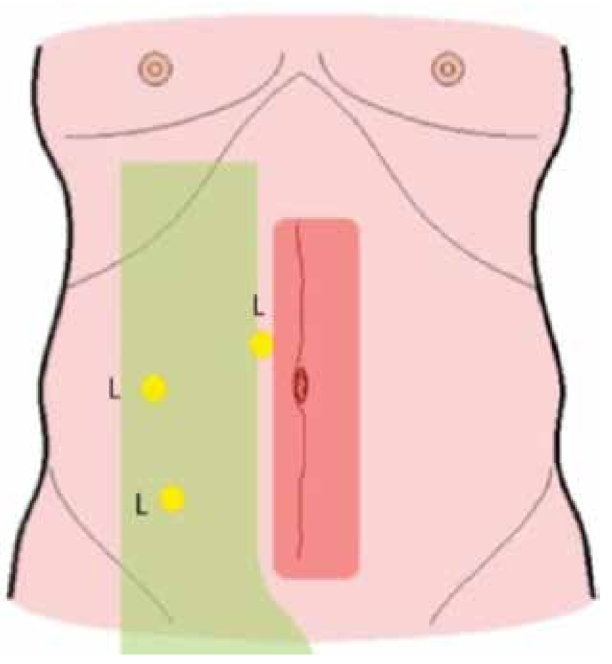

Figure 4. Port positions for multiport laparoscopic Hartmann's reversal. L = laparoscopic trocar position. *Red-shaded area*: area of maximal adhesion formation after previous laparotomy. *Green-shaded area*: area of range of action that is relatively free of adhesions. Note that in this technique the midline has to be crossed.

3.2. The open technique compared to multiport laparoscopic restoration technique: an appraisal of the literature

In recent literature a limited amount of studies compared an open approach with the multiport laparoscopic technique [22–31]. In **Table 1** a summary of studies on multiport laparoscopic versus conventional Hartmann's reversal is presented.

As expected, for the minimal invasive technique, the total length of hospital stay was shorter with 6.9 days when compared to the open approach that shows a mean of 10.4 days. Furthermore, for patients in whom bowel continuity was restored laparoscopically, overall morbidity rates seemed lower when compared to patients who were treated conventionally. In the laparoscopic group, mean morbidity rates were 12% versus 20% in the open group. The main and foremost complications after bowel restoration for both modalities are summarized in **Table 2**.

In the reviewed literature, mortality seems comparable for both techniques, with a mean mortality of 0.9% in the laparoscopic group and 1.2% in the conventional group. No statistically significant differences were found for mean total operation time, 150 minutes for the laparoscopic technique and 172 minutes for conventional procedures. A possible explanation for the relative long operation duration for both techniques is the extensive adhesiolysis that is required. 80 percent of the conversions from laparoscopy to the conventional technique arises for this reason [33], resulting in an average conversion rate of 12 percent. In the opinion of the authors, there is no place for primary open restoration of continuity after Hartmann's

Study	Country	Year of publication	Procedure	Number of patients	Morbidity (%)	Mortality (%	Operation time (mean min)	Hospital stay (days)	Control group (number of patients)	Morbidity (%)	Mortality (%)	Operation time (mean min)	Hospital stay (days)
Rosen et al. [24]	USA	2005	Laparoscopic	20	3 (14)	0 (0)	158	4.2	No				NS
Faure et al. [25]	FR	2007	Laparoscopic	14	2(14.2)	0 (0)	143	9.5	Conventional (20)	6 (30)	0 (0)	180	11
Haughn et al. [26]	USA	2008	Laparoscopic	61	8 (13)	0 (0)	154	NS	Conventional (61)	11 (18)	0(0)	210	NS
Vermeulen et al. [27]	NL	2008	Laparoscopic	3	(15.8)*	(5)*	NS	NS	Conventional(48)	(15.8)*	(5)*	NS	NS
Mazeh et al. [28]	IL	2009	Laparoscopic	82	15 (17.6)	0 (0)	193	6.5	Conventional (41)	15 (36.5)	0 (0)	209	8.1
Di Carlo et al. [29]	IT	2010	Laparoscopic	3	0 (0)	0 (0)	95.6	NS	Conventional (3)	0 (0)	0 (0)	136.6	NS
De'angelis et al. [30]	FR	2013	Laparoscopic	28	3 (10.7)	0 (0)	171.1	6.7	Conventional (18)	6 (33.6)	0 (0)	235.8	11.2
Yang et al. [31]	AU	2014	Laparoscopic	43	6 (14)	0 (0)	276.4	6.7	Conventional (64)	20 (31)	0 (0)	242	10.8

AU, Australia; FR, France; IT, Italy; IL, Israel; NL, the Netherlands; USA, United States of America; NS, not stated.In the study by Vermeulen et al. [32]. Subdivision is made for laparoscopic or conventional reversal; therefore, only overall morbidity and mortality are given for this study.

Table 1. Summary of current literature that compares multiport laparoscopic Hartmann’s reversal versus the conventional open technique.

	Type of intestinal continuity restoration	
	Multiport laparoscopy	Laparotomy
Hemorrhage	1.7	3
Wound infection	10.6	14
Anastomotic leakage	1.2	5
Reoperation	4	7
Cardiopulmonary	3.6	7

Values are derived from the literature. Values are in mean percentages.

Table 2. Morbidity rates depicted for multiport laparoscopic reversal of Hartmann's procedure compared with conventional reversal.

procedure, due to unnecessary morbidity, mortality, and trauma to the abdominal wall. We advocate selection of a minimally invasive procedure.

4. Trephine access: using the former colostomy site as access point

Although laparoscopic restoration of the intestinal continuity has many advantages, in laparoscopic reversal of Hartmann's procedure, an extended adhesiolysis in the midline and pelvis is still needed. This adhesiolysis may increase postoperative paralytic ileus and the risk of inadvertent bowel lacerations.

The use of the colostomy site as an even less invasive method for access to the abdominal cavity and restoration of the intestinal continuity was first described by Vermeulen and colleagues in 2008 [32]. In this technique manual access is gained through the stoma site in combination with a blindly performed adhesiolysis without laparoscopic assistance (**Figure 5**). This procedure was called the SIR method "stoma incision reversal" procedure.

4.1. SIR procedure: surgical technique

The patient is positioned in the lithotomy. The stoma is released, taking a small amount of surrounding skin with it. Then the colostomy is closed provisionally with a running suture. The length of the incision at the stomal site must be large enough to fit the surgeon's hand. The descending colon stump is brought outside the abdomen; visible adhesions connected to the left colon are sharply dissected. Further adhesiolysis of the left colon is performed manually between the thumb and index finger in order to create enough length for the descending colon to reach the pelvic cavity. If enough bowel length is created. The anvil of a circular stapler is placed intraluminal. The stump is closed using a linear stapler. The tip of the stapler anvil is brought through the colon the staple line and tied by a purse-string suture. The descending colon with the anvil is returned intra-abdominally. For the next step, the surgeon's right hand is placed intra-abdominally through the former colostomy side. The left hand is used to transanally introduce a rigid sizer to identify and manipulate the rectal stump. Adhesions between the rectal stump and adjacent small bowels are loosened manually and blindly with the surgeon's right hand. Consecutively, the circular stapler is introduced into

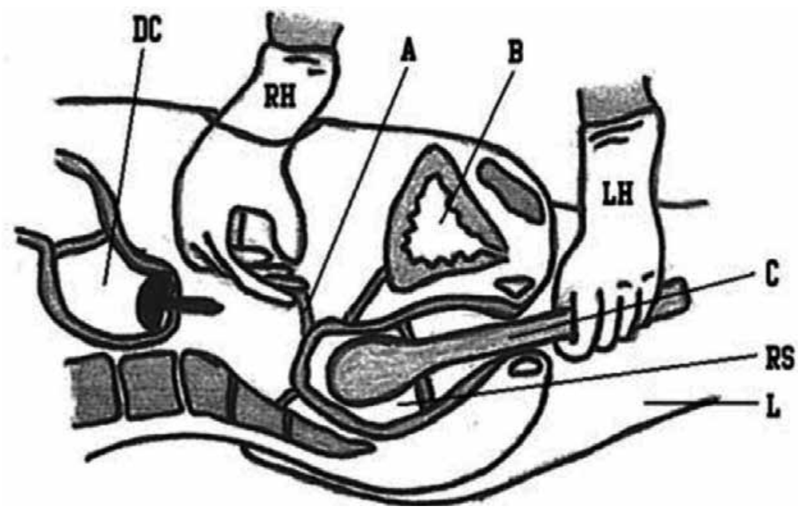

Figure 5. Manual lysis of adhesions at the tip of the rectal stump, which was identified using a rigid club. Previously, the anvil of a circular stapler was placed intraluminal of the descending colon. DC, descending colon with anvil; RH, right hand; A, adhesions; B, bladder; LH, left hand; C, rigid club; RS, rectal stump; L, left leg. Source: Ref. [34].

the rectal stump. The pin of the circular stapler is passed through the rectal wall, and the anvil is attached. Before firing the circular stapler, the proximal bowel segment is manually checked for rotation and interposition. After firing the stapler, the integrity of the doughnuts of the anastomosis is inspected, and a leak test is performed. The fascia is closed with a PDS suture, and the skin as deemed appropriate.

4.2. Appraisal of the literature

A review of the literature shows three studies [32, 34–36] on the SIR technique. **Table 3** summarizes the results. Vermeulen and colleagues described the first pilot study in 2010. They attempted the procedure in 13 consecutive patients with a median age of 56 years (range 35–81 years). Indications for initial surgery were iatrogenic bowel perforation (n = 3), intestinal bowel obstruction due to complicated diverticulitis (n = 3), and diverticulitis (n = 7). Median delay of reversal was 7 months.

Of the 13 patients assigned for reversal of Hartmann's procedure through the stomal site, two patients needed direct conversion to laparotomy due to firm adhesions. Of the 11 patients in which the procedure was accomplished through the stoma site, mean operation time was 81 min (range 58–109 min) with a mean hospital stay of 4.2 days. No anastomotic leaks occurred. In 2010 Vermeulen and colleagues published the results of their "stoma incision reversal" procedure in 22 patients and compare the results with matched cases in which restoration of the intestinal continuity was performed by laparotomy. In the "SIR" group, five procedures were converted to laparotomy due to firm adhesions (n = 2), doubt about the quality of the doughnuts (n = 2), or iatrogenic small bowel lacerations (n = 1).

In this study the mean operation time was significantly shorter when performing the SIR procedure (75 min (58–208)) compared to the open group (141 min (85–276)) (p < 0.001). Patients

Study	Country	Year of publication	Number of patients	Procedure	Control group (number of patients)	Morbidity (%)	Mortality (%)	Operation time (mean min)	Hospital stay (days)
Vermeulen et al. [32]	NL	2008	13	Trephine access	No (0)	0 (0)	0 (0)	81	4.2
Vermeulen et al. [34]	NL	2010	16	Trephine access	Yes (32)	4 (25)	0 (0)	75	4
Aydin et al. [35]	TR	2011	8	Trephine access	No (0)	0 (0)	0	65	5.5

NL, the Netherlands; TR, Turkey.

Table 3. Summary of “trephine access” technique reversal of Hartmann’s procedure in the current literature.

	Type of intestinal continuity restoration	
	"SIR"	**Laparotomy**
Total complications	4	16
Anastomotic leakage	1	2
Ileus	0	1
Wound infections	1	5
Urine retention	1	0
Incisional hernia	1	8
Mortality	0	1

Vermeulen et al. 2010 [35].

Table 4. Postoperative complications after restoration of bowel continuity depicted for the "SIR" procedure (trephine access) and conventional technique.

who underwent the SIR procedure had a shorter postoperative hospital stay (SIR group range 2-7 days) ($p < 0.001$). The total postoperative number of complications was not significantly different between both procedures. Twenty-five percent for the SIR patients versus 50% of the patients that were treated by the conventional technique. Postoperative complications after bowel continuity restoration are depicted in **Table 4**.

In 2011 Aydin and colleagues perform the aforementioned technique in eight patients. Indications for the initial Hartmann's procedure were sigmoid volvulus ($n = 4$), obstructive sigmoid cancer ($n = 2$), rectal trauma ($n = 2$), and Fournier's gangrene ($n = 1$). The mean duration between the primary procedure and reversal of the Hartmann's procedure was 5 months (range 2–8 months). All patients included had a body mass index of less than 30 km/m^2 and a rectal stump of at least 5 cm. In two patients the incision was extended from the stoma site for better visualization of the rectal stump in one patient and due to injury of the intestine in one patient. Mean duration of the operation was 65 min (range 45–80 min). No postoperative complications were observed. Patients were discharged after a mean of 5.5 days (range 4–9 days). Aydin and coworkers note that this technique should ideally be used in non-obese patients with long rectal stumps of sufficient length.

The SIR technique originated in the Netherlands and met criticism due to the blind nature of the dissection phase of the procedure. Regarding the risk of blind dissection as well as the availability of improved access platforms that enable adequate vision and control, the authors do not advocate the use of the SIR technique in present times.

5. Single-port restoration of the intestinal continuity through the stoma trephine site

Single-port restoration of intestinal continuity with access through the formal site of the colostomy is a relatively new technique. The main goal for the development of this method is introducing a minimally invasive technique that further reduces the morbidity and mortality of a procedure that is technically demanding and complex.

5.1. Surgical technique

The patient is placed in lithotomy position. Primarily, the colostomy is mobilized and freed from the fascia (**Figure 6**). The mobilized descending colon is then pulled out of the abdomen and exposed (**Figure 7**). Next, the colon is transected using a linear stapler to remove the end colostomy, and the anvil of a circular stapler is secured with a purse-string suture, in the proximal colon. Either a terminal or lateral position can be chosen (**Figure 8**). The descending colon is returned into the abdominal cavity. Any adhesions close to the wound in the abdominal cavity on direct view are freed. The single-port access platform is then placed in the fascial defect at the colostomy site, and the pneumoperitoneum is then established (**Figure 9**). A rigid 30-degree laparoscope is introduced and a diagnostic laparoscopy is performed. Subsequently, the patient

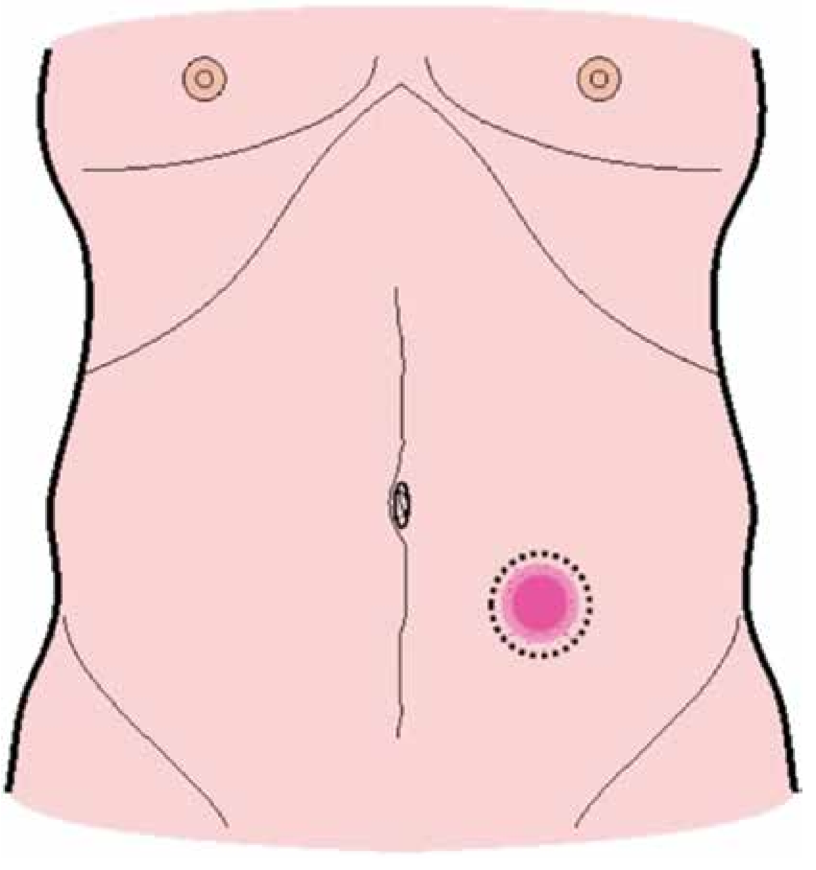

Figure 6. Release of the colostomy.

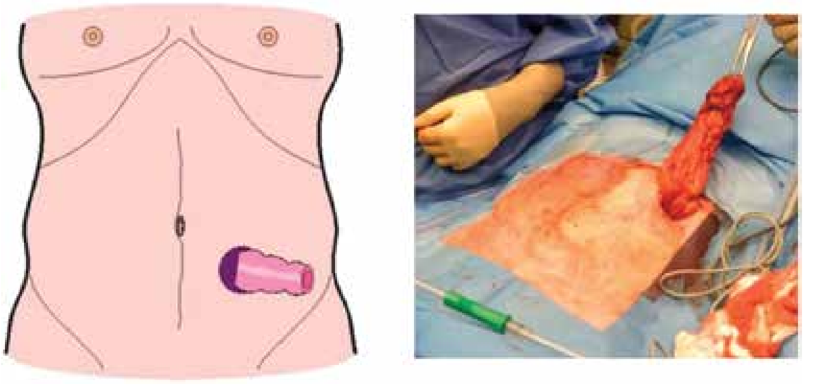

Figure 7. Mobilization of the descending colon with sufficient length.

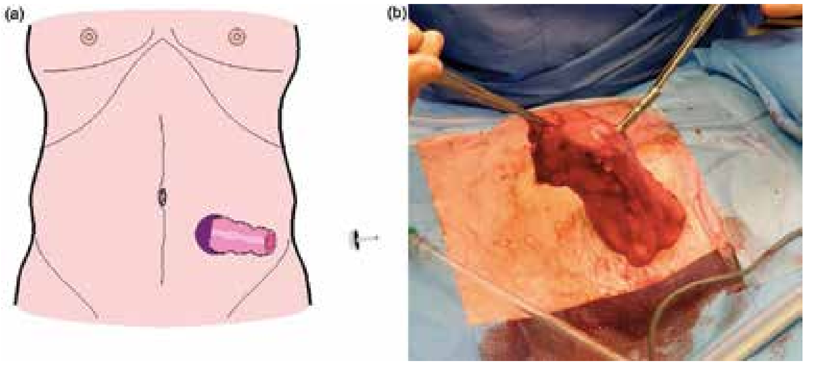

Figure 8. Insertion of the anvil of the circular stapler. Left picture shows a terminal position. Right picture shows a lateral positioning of the anvil for side-to-end configuration.

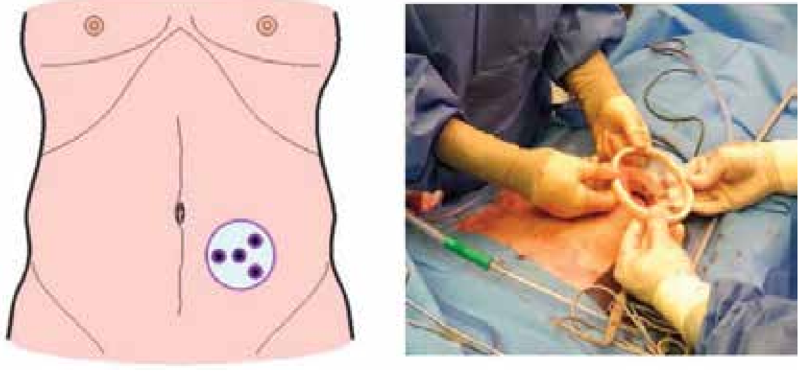

Figure 9. Placement of the single-port access device in the fascia defect at the formal stoma site. Right picture shows the placement of the flexible wound protector.

is positioned in anti-Trendelenburg position making the small pelvis visible. Adhesiolysis is performed using two 5 mm working trocars.

Dissection of adhesions and scar tissue surrounding the rectal stump is performed extensively, by either sharp dissection with laparoscopic scissors or ultrasonic dissection devices, until the rectal stump is as bare as possible (**Figure 10**). Adhesions formed at the previous midline incision can be left unchanged at this stage, reducing the risk of iatrogenic bowel perforation and reducing total operation time. Next, the circular stapler is advanced via the anus, and the descending colon is identified and checked if adequate length is available to allow a tension-free anastomosis. If necessary, the splenic flexure of the colon can be mobilized (**Figure 11**). The stapler is deployed and the donuts are checked. The pneumoperito-

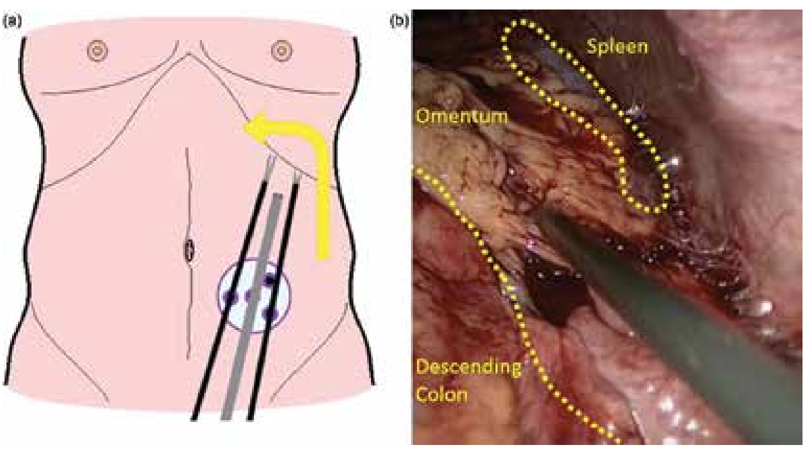

Figure 10. Adhesiolysis and mobilization of the splenic flexure.

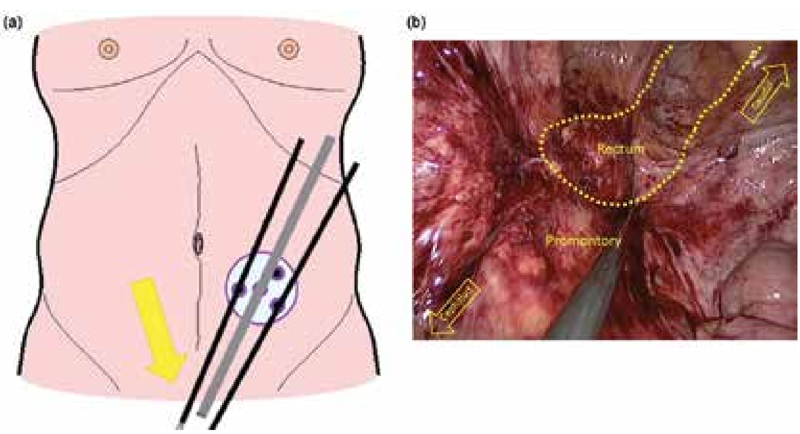

Figure 11. Dissection of adhesions and scar tissue surrounding the rectal stump.

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Study	Country	Year of publication	Number of patients	Procedure	Control group (number of patients)	Morbidity (%)	Mortality (%)	Hospital stay(days)
Smith et al. [42]	USA	2011	1	Stoma site. Single port	No (0)	0(0)	0(0)	5
Carus et al. [39]	GE	2011	8	Stoma site. Single port	No (0)	1 (12.5)	0 (0)	4
Borowski et al. [38]	UK	2011	5	Stoma site. Single port	No (0)	1 (20)	0	4.2
Joshi et al. [41]	UK	2013	14	Stoma site. Glove port	No (0)	3 (21)	0 (0)	5.5
Choi et al. [40]	KR	2015	22	Stoma site. Glove port. Single port	No (0)	4 (18.2)	0(0)	8
Clermonts et al. [37]	NL	2016	25	Stoma site. Single port	Yes (16)	8 (32)	0 (0)	4

KR, Korea; NL, the Netherlands; UK, the United Kingdom; GE, Germany; USA, the United States of America.

Table 5. Summary of single-port reversal of Hartmann's procedure in the current literature.

neum is released and the trocars are removed under direct visualization. The fascia is then closed in apertures equal to or larger than 10 mm.

5.2. Appraisal of the literature

A review of the literature reveals that only a few small case series have been published on this technique. At the moment no randomized controlled trials were published [37–42]. **Table 5** summarizes the results of the available literature. The technique was first described by Smith and colleagues [42]; in this case single-port restoration of the intestinal continuity was performed in a 56-year-old patient with a history of perforated diverticulosis. Their total operation time was 104 min. The patient started a clear liquid diet on postoperative day 2 and was discharged after 5 days. The largest study without control patients was that of Choi et al. [40] and consisted of 23 patients. In one patient closure of the colostomy was aborted due to intraoperative difficulties. The median age of their patients was 62 years (range 21–87 years), with an overall ASA grade of II. Median time to reversal was 153.5 days (range 99–1028). Main indications for Hartmann's procedure were: complicated diverticulitis (27.3%), colorectal carcinoma (27.3%), and sigmoid volvulus (18.2%). They reported a median operation time of 165 minutes (range 100-340 minutes) and a total hospital stay of 8 days (range 4–31 days). There morbidity rate was 18.2% with two reoperations, one for anastomotic dehiscence and one for rectovesical fistula. No mortality was reported. Carus and colleagues' study consisted of 8 patients with a median age of 60.4 years (range 36–84). Hartmann's procedure was performed for complicated diverticulitis (five laparoscopic, three open). The reversal was performed 2–4 months after the primary procedure. No conversions were reported in one procedure; they had to play one extra trocar had to be placed during adhesiolysis; and one patient with a superficial wound infection (morbidity 12.5%). No mortality was reported. Patients were discharged after a median of 6.4 days (range 4–8 days). The series by Clermonts et al. [37] was the only study that included a control group. They included a total of 25 patients (median age, 52.2 years). Indications for primary surgery consisted of complicated diverticulitis (60%) and malignancy in 28% of the cases. Median time to reversal was 16 months. These patients were compared with a control group in which closure of the colostomy was performed in an open method. In the open group, all primary Hartmann's procedures were performed by laparotomy; in the single-port group, 88% was performed by laparotomy. No statistical significant differences were observed between the two groups. Median operation time in the single-port group

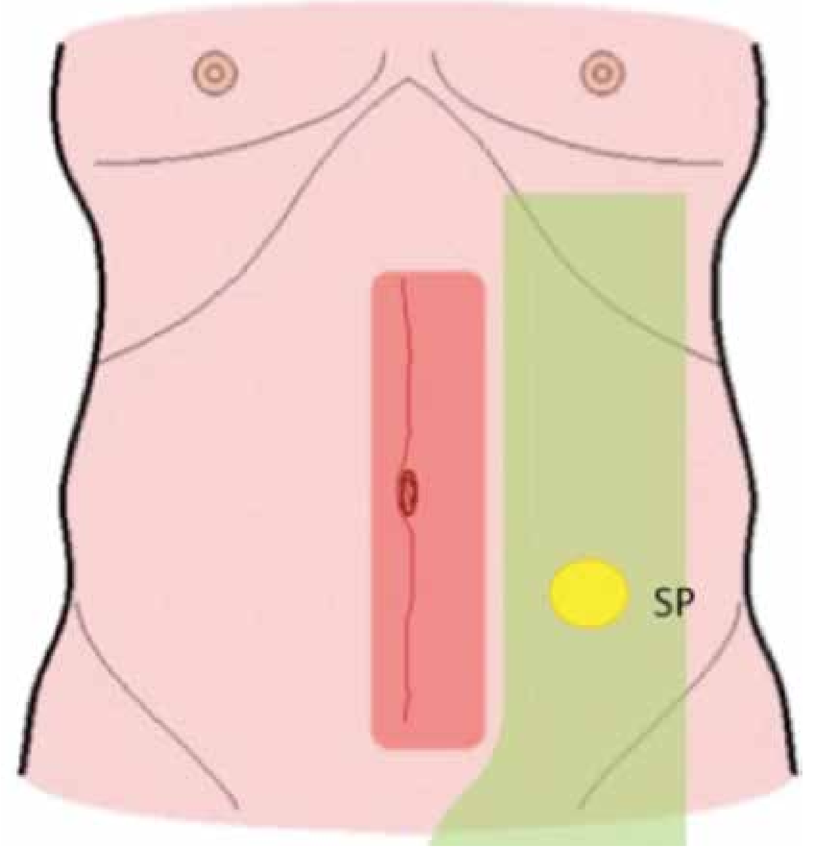

Figure 12. Port position for single-port Hartmann's reversal. SP = single-port trocar position. *Red-shaded area*: area of maximal adhesion formation after previous laparotomy. *Green-shaded area*: area of range of action that is relatively free of adhesions.

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was 153.5 min (range: 73–332 minutes) and 184.4 min (range 29–377 minutes) in the open group. One single-port procedure was converted to laparotomy and two procedures to multiport laparoscopy due to difficulties during the adhesiolysis. In the single-port group, a total of eight complications were observed compared with 33 complications in the open group. Wound infections, 5 (20 %) versus 12 (75 %), accounted for the largest number of complications in the SPHR and OHR groups. One patient died after anastomotic leakage and sepsis in the control group; no mortality was observed in the single-port group. The median hospital stay was 4 days in the single-port group compared to a mean of 16 days in the open group.

5.3. Advantages of this technique

Single port restoration of the intestinal continuity has some major advantages over the previously mentioned techniques. The minimally invasive technique has the usual advantages of this technique with less pain and faster recovery. Specifically, in Hartmann's reversal also a shorter operation time is observed. The single port variant using the formal stoma site as an access point has the additional advantage that crossing the midline is avoided, rendering an extensive adhesiolysis unnecessary as **Figure 12** schematically shows.

Another big advantage of minimalizing the access trauma is shown in the very short hospital stay compared to the open and laparoscopic techniques. The small incision, almost no blood loss, and short operation time could be the main reasons.

6. Single-port trephine access and transanal access combined for restoration of the intestinal continuity

In Section 5 we already described the advantages of single-port restoration of intestinal continuity with access through the formal site of the colostomy. Recently, a new technique that combines the single-port trephine access with single-port transanal access was presented [43]. It is suggested the transanal approach will aid in the technically challenging dissection of the rectal stump and perform a pelvic adhesiolysis in a safer manner.

6.1. Surgical technique

Patients receive mechanical bowel and rectal stump cleansing. Patients are placed in lithotomy position. The procedure is performed by two surgeons starting simultaneously; one surgeon starts the abdominal trephine access approach (Section 5). The second surgeon places a single-port transanal access platform through the anal canal with three working trocars. The pneumorectum is created. Next, circular dissection next to the stapler line in the proximal part of the rectal stump is performed into the avascular presacral plane posteriorly. This plane of dissection is extended medially, laterally, and interiorly to achieve the desired circumferential rectal mobilization. Finally, the peritoneal reflection was visualized and divided to achieve the proximal rectal stump removal, with both surgeons working together. The previous stapler line with the resected tissue can be extracted transanally. Next, a Prolene purse-string suture is used to close the distal rectal stump. In order to complete the end-to-end anastomosis, a circular stapler is inserted via the anal canal and connected to the anvil in the proximal descending colon. After firing the circular stapler and completing the anastomosis, the integrity of the anastomosis can be evaluated with an air test, as well as an intraluminal examination through the transanal access platform.

6.2. Critical appraisal of literature

A review of the literature reveals one study by Bravo and colleagues [43]. The study group describes a technique that is easily adopted and mastered by surgeons already trained in transanal colorectal surgery. They report no postoperative morbidity and a quick recovery and discharge from the hospital (no exact numbers given). Furthermore, a shorter total operation time is mentioned when compared to a multiport laparoscopic approach.

Advantages of this technique mentioned by the authors are first of all the safe dissection of the rectal stump because most of the work is done in a surgical plane not touched during the initial surgery and thus without adhesions. This gives the ability to precisely identify structures with adherence to the rectal stump like small bowel or ureter. The main difficulty of this technique can be performing the transanal dissection in patients with hard adhesions to the rectal stump after perforation or peritonitis. Furthermore, a very short rectal stump makes positioning the transanal single-port access difficult and without adequate workspace impossible.

7. Authors' recommendation

The authors believe that the minimally invasive technique is an attractive approach for rever-sal of Hartmann's procedure. So far, reports are promising. The technique may reduce the substantial morbidity known from open reversal. The SIR technique may be considered to be obsolete, especially in the era of laparoscopy. Most patients will be best suited by use of lapa-roscopic techniques. We would like to emphasize that laparoscopy is a means to an end and not a goal in itself. If minimally invasive techniques are deemed unsafe or unsuitable, conver-sion to open technique may be utilized at any time. We believe that. The recently developed technique of single port restoration of continuity seems especially promising, as contralateral access that can be cumbersome due to the adhesions from a previous laparotomy is avoided and a ventral hernia defect when present can be avoided. We believe Trephine assess in combination with the transanal approach as primary surgical approach is not always necessary. We recommend this technique to be used as a step-up approach or back-up when pelvic dissection is proving technically challenging

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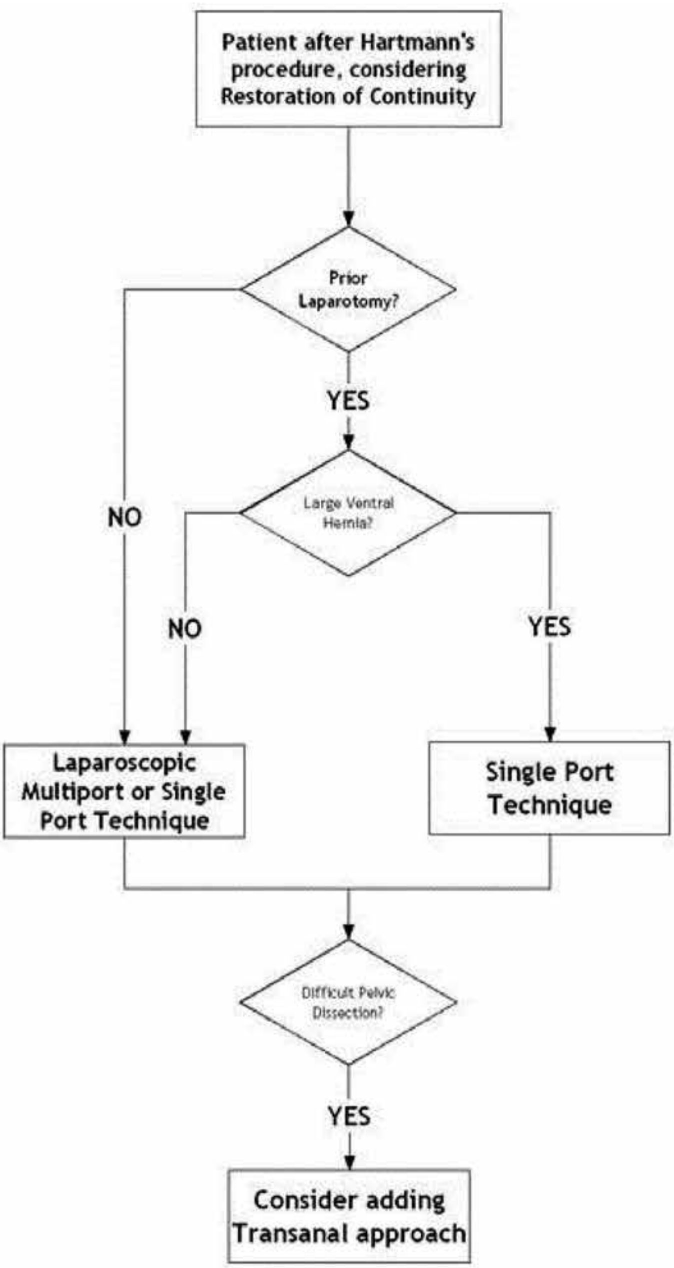

Figure 13. Algorithm to be used during the decision-making which technique is best suited for the restoration of bowel continuity after Hartmann's procedure.

or unsafe during initial trephine or multiport access. Authors recommendations are summarized in the algorithm in **Figure 13**.

8. Conclusion

The reversal of Hartmann's procedure carries a high operative morbidity and mortality rate. Therefore this is only performed in a selected group of patients. A considerable group of patients, with advanced age, or expected high operative risk, are left with a permanent end colostomy. This chapter gives an overview of the development less invasive techniques, that may reduce morbidity and therefore be offered to a larger group of patients.

Conventional laparoscopic reversal of Hartmann's procedure was the first technique with the primary goal of reducing morbidity and mortally. This technique reduced surgical access trauma resulting in a shorter post operative hospital stay and avoiding the negative consequences of relaparotomy. In the quest for even less invasive ways of restoring the bowel continuity the Trephine access technique was developed. This technique received criticism on the fact that the adhesiolysis was performed mainly in a blind fashion. This is probably the reason why this technique has not gained wide popularity and acceptance. This technique however gave birth to the development of the single-port access technique. This minimally invasive laparoscopic technique has our preference. We recommend using this technique for the major reduction in access trauma. Avoiding crossing the midline reduces the need for adhesiolysis, with its potential hazards like iatrogenic bowel injury. When proven safe in larger series, reversal of Hartmann's procedure may be offered to a larger proportion of patients then is presently routine.

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Chapter 2

Bariatric and Metabolic Surgery

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Prasad M. Bhukebag and Khan Wei Chan

Additional information is available at the end of the chapter

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Abstract

Obesity as a global epidemic has rapidly increased in incidence in the recent few decades and represents one of the biggest public health challenges. Obesity plays a major risk for various diseases such as cardiovascular disease (CVD), diabetes mellitus (DM), hypercholesterolemia, osteoarthritis and some form of cancers. Bariatric and metabolic surgery provides the best solution for obesity and its associated comorbidities. This chapter will discuss in detail the commonly performed bariatric and metabolic surgeries.

Keywords: bariatric surgery, metabolic surgery, Roux-en-Y gastric bypass, sleeve gastrectomy, duodenojejunal bypass, proximal jejunal bypass, obesity, type 2 diabetes

1. Introduction

Bariatric surgery has been established to be the most effective treatment for morbid obesity, producing sustained and durable weight loss with improvement or remission of comorbidities and longer life [1]. The procedures undertaken to treat morbid obesity have changed over a period of time and recently newer procedures are being developed with lesser morbidity and mortality and better results. The resolution of comorbidities such as type 2 diabetes mellitus (T2DM), hypertension and others after bariatric surgery gave impetus to the concept of metabolic surgery. Metabolic surgery has become increasingly effective and accepted option for patients with T2DM [2]. This chapter will describe in detail two most commonly performed procedures, laparoscopic sleeve gastrectomy (LSG) and laparoscopic Roux-en-Y gastric bypass (LRYGB). Part of the chapter also details the sleeve gastrectomy-based procedures which include sleeve gastrectomy with loop duodenojejunal bypass (LDJB-SG) and sleeve gastrectomy with proximal jejunal bypass (SG-PJB).

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2. Laparoscopic sleeve gastrectomy

Laparoscopic Sleeve Gastrectomy (LSG) or "sleeve" is now one of the most commonly performed bariatric procedures worldwide. It is a purely restrictive procedure without intestinal bypass. In 1999, Michel Gagner and his team performed the first laparoscopic duodenal switch on the porcine model and found it to be feasible. Laparoscopic duodenal switch was later performed in morbid obese patients and found to have higher morbidity in higher BMI patients. Staged procedure was then undertaken to reduce the mortality and morbidity with laparoscopic sleeve gastrectomy as the first stage of a two-stage duodenal switch. However, the initial weight loss after LSG alone was found to be adequate and maintained over a period of time. The second stage of surgery was deferred or was not required at all and patients maintained good weight loss with just the first stage. After this success and some modifications to the procedure, sleeve gastrectomy was established as an effective stand-alone bariatric procedure.

Apart from restriction of size of stomach, reduction in the "hunger hormone" ghrelin, after LSG decreases appetite. Advantages of LSG include lower operative complexity, relative safety and maintenance of pylorus and easy convertibility to other procedures. Also, since there are no bowel bypass problems of internal herniation, small bowel obstruction, micronutrient deficiencies and malnutrition will not be encountered.

The disadvantages of the procedure include irreversibility, possibility of staple line leak, bleeding and stricture of gastric tube. The incidence of gastroesophageal reflux has also been found to be increased in some patients undergoing this procedure.

2.1. Indications and contraindications

Indications for this procedure include BMI ≥ 40 kg/m^2 without comorbidities or ≥35 kg/m^2 with comorbidities. This can also be offered as a first stage of biliopancreatic diversion in patients with BMI > 50 kg/m^2. Contraindications include chronic alcoholism, drug and substance abuse, major psychiatric disorder, severe gastroesophageal reflux disease and chronic duodenal ulcer.

2.2. Preoperative work up and preparation

Comprehensive preoperative workup for sleeve gastrectomy is the same as that of the other bariatric procedures. Patients are admitted the day prior to the procedure when they are started on clear liquid diet. Single dose of prophylactic antibiotic and proton pump inhibitor are given an hour prior to surgery. Low molecular-weight heparin (LMWH) is prescribed to lower the incidence of deep vein thrombosis (DVT) and other thromboembolic events, till the patient is ambulated.

2.3. Operative technique

2.3.1. Positioning

Patient is positioned flat on the operating table with both upper extremities extended out. Patient is secured at the chest and thighs using straps and a foot board in preparation for a steep reverse Trendelenburg position. The surgeon and the scrub nurse both stand on the patient's right while the first assistant and the cameraman stand on the patient's left.

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2.3.2. Port placement

A three-four ports technique is utilized for this procedure as shown in **Figure 1**. Pneumoperitoneum is created by Veress needle or optical trocar is used at the first port. The first port is about three finger breadths to the left of umbilicus, at about 20 cm from the xiphisternum. The second 15 mm port is inserted at supraumbilical site. Another 5 mm trocar is inserted in the right midclavicular line below the costal margin, for surgeon's left hand, such that the falciform ligament does not cause difficulty in dissection of the hiatus. Lastly an optional 5 mm assistant port can be placed in the left anterior axillary line just below the costal margin.

2.3.3. Placement of liver suspension tape

To elevate the central and left lobe of the liver, a liver suspension tape (LST) was designed. Two pieces of Jackson-Pratt (JP) drain measuring 2 cm each were cut and fixed with 2/0 polypropylene suture (Ethicon W8400 2-0 Prolene blue 70 mm round bodied). The lateral segment of the left lobe was suspended using the tape by passing the needle through the liver, out through the anterior abdominal wall and secured with clamps. Another LST was inserted in the medial aspect of left lobe of liver to retract the liver completely.

The LSTs should not be placed more than 2 cm away from the liver edge to achieve optimal retraction and prevent major bile duct or vessel injury (**Figure 2**). Alternatively, a Nathanson

Figure 1. Port placement for LSG.

liver retractor (C-NLRS-1001 Cook Medical) may be used in order to achieve good exposure of the entire length of the stomach and duodenum. This may be placed using a 5 mm port inserted in the subxiphoid area.

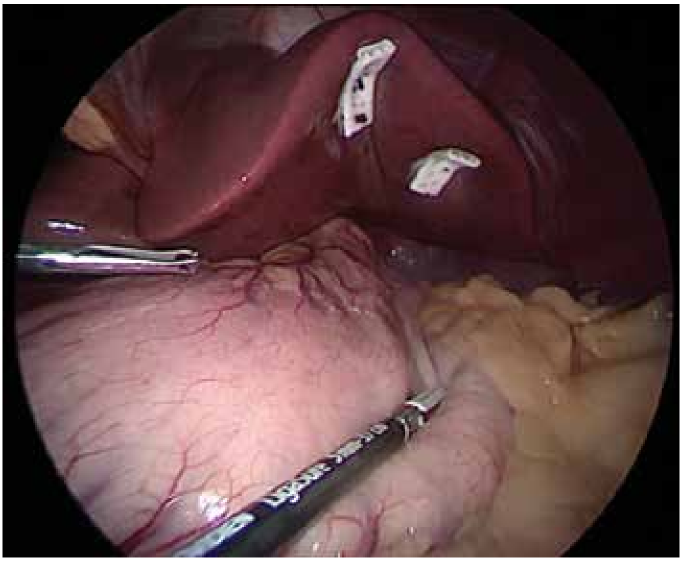

Figure 2. Retraction of left lobe of liver with liver suspension tape.

2.3.4. Mobilization of the gastrocolic ligament

Dissection of the gastrocolic ligament close to the greater curvature of the stomach commences at a point opposite the incisura angularis. A window in the lesser sac is created and dissection is started using a vessel sealing energy device (Ligasure™ vessel sealing device by Covidien-Medtronic or Harmonic Ace by Ethicon). By staying very close to the gastric wall, the entire gastrocolic ligament is detached up to the angle of His taking care at the area of the short gastric vessels at the splenic hilum (**Figures 3** and **4**). Care should be taken not to injure left gastric vessels.

2.3.5. Dissection at the angle of His

Fundus of the stomach must be mobilized from its adhesions and completely resected. A very useful anatomical landmark is to expose the left crus of the hiatus. Dissection of the left crus is terminated once the left phrenoesophageal ligament has been completely visualized (**Figure 5**). The posterior attachments of the fundus to the anterior border of the pancreas are completely mobilized to properly identify and preserve the left gastric vessels (**Figure 6**).

The anterior portion of the gastroesophageal fat pad (Belsey's pad of fat) is then dissected in order to expose half of the anterior portion of the GE junction. Care is taken not to completely devascularize this fat pad which may increase the rate of leak at the GE junction.

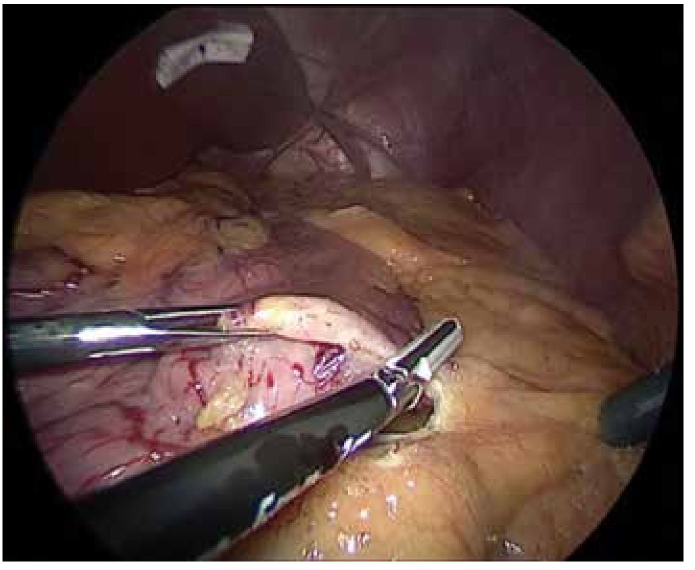

Figure 3. Start of dissection by creating a window in the lesser sac.

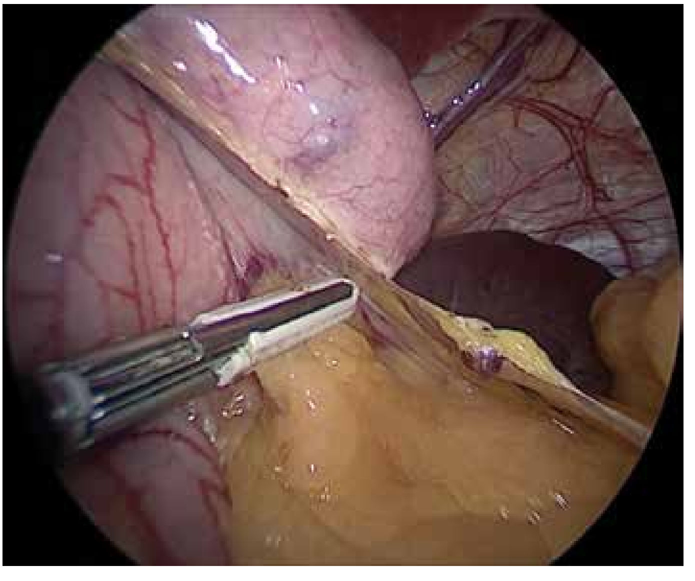

Figure 4. Dissection of the gastrocolic ligament at short gastric vessels near splenic hilum.

2.3.6. Dissection of the caudal part of the gastrocolic ligament

The gastrocolic ligament at the area of the right gastroepiploic vessel is dissected caudally till the distance of 4 cm from the pylorus. Dense adhesions around the prepyloric area may be encountered and should be taken down individually (**Figure 7**).

2.3.7. Sleeve gastrectomy

Prior to the creation of the actual sleeve, make sure that the entire stomach is laid down flat. At this point, the anesthesiologist inserts an orogastric tube with its tip positioned by the surgeon under direct visual guidance. Using an L-hook dissector (STORZ 37370DL Monopolar Dissecting L-Hook Cannula), marking on the anterior surface of the stomach is done which

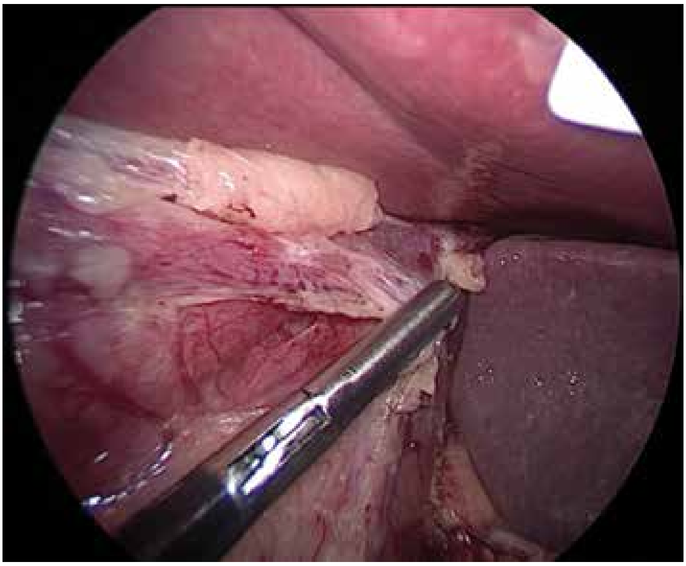

Figure 5. Dissection at the angle of His exposing the left crus and phrenoesophageal ligament.

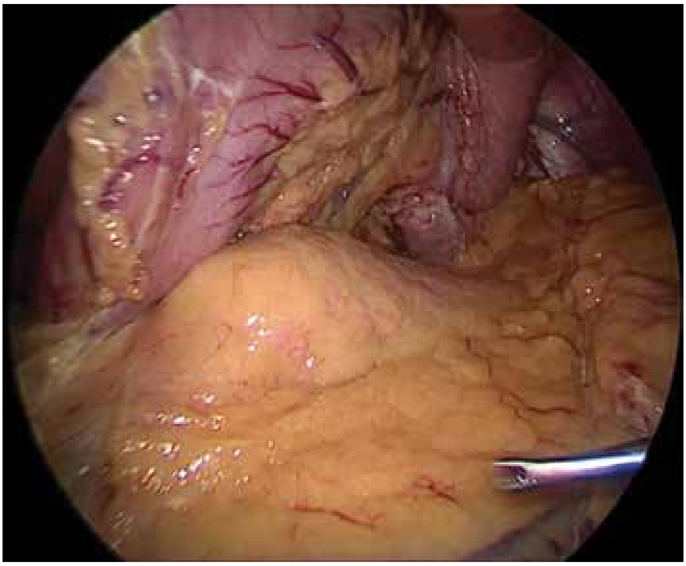

Figure 6. Complete mobilization of the posterior attachments of the fundus and anterior border of the pancreas.

will serve as a guide for the surgeon to place the endostapler with 38 Fr orogastric tube as stent (**Figure 8**). For the first staple firing, the stapling device is placed 4 cm away from the pylorus and 2.5–3 cm away from the incisura angularis in order to prevent narrowing (**Figure 9**). A black 60 mm reload (EGIA60AXT Endo GIA 60 mm articulating extra-thick reload with Tri-Staple Technology) or a green 60 mm green reload (ECR60G Echelon Endopath stapler reload cartridges by Ethicon) using manual or powered device is used. Successive firings

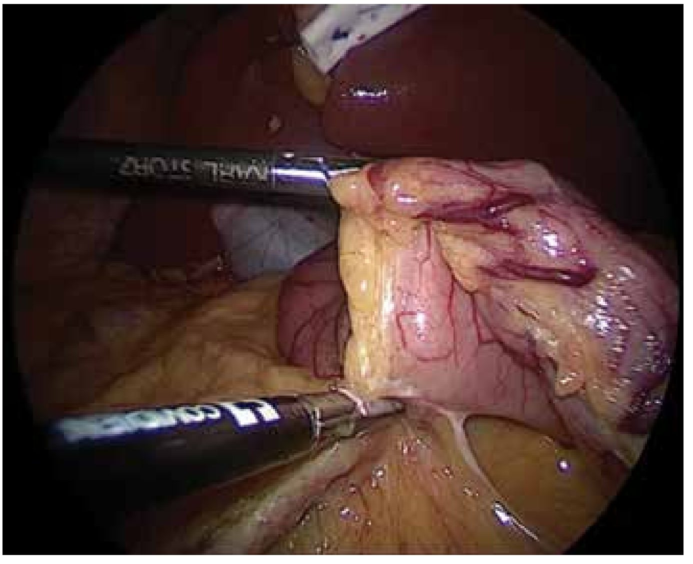

Figure 7. Dissection of the gastrocolic ligament toward the pylorus.

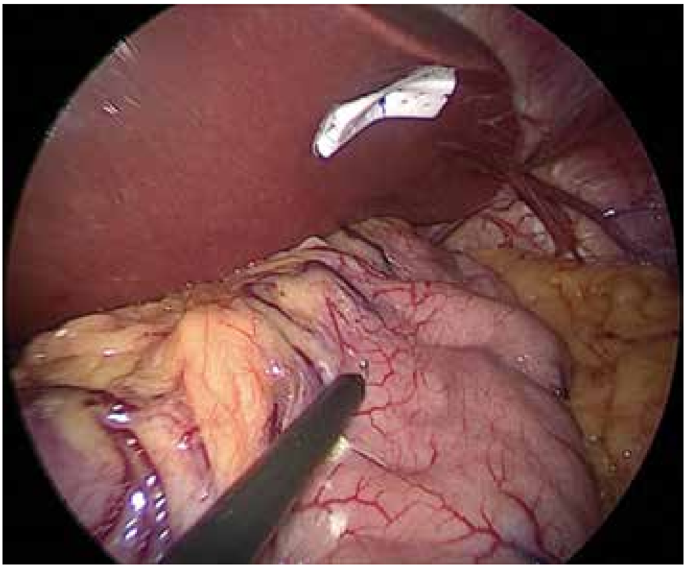

Figure 8. Marking of the transection line along the anterior surface of the stomach.

of the stapling device toward the gastric fundus are done using either a 60 mm purple cartridge (EGIA60AMT Endo GIA 60 mm articulating medium/thick reload with Tri-Staple Technology) or a 60 mm blue cartridge (ETHECR60B Echelon Endopath stapler reload cartridges by Ethicon) (**Figure 10**). Commencing after placement of the second stapler, loose migratory crotch staples must be removed in order to prevent improper formation of the

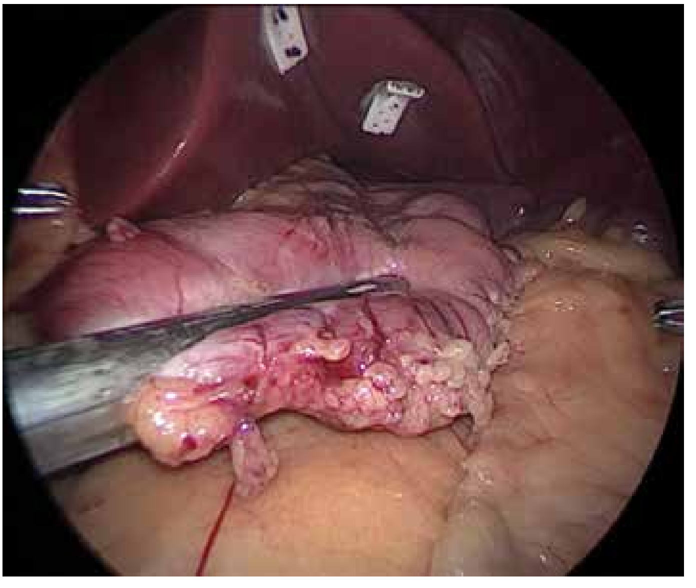

Figure 9. First staple firing 4 cm from pylorus and 2.5–3 cm away from the incisura.

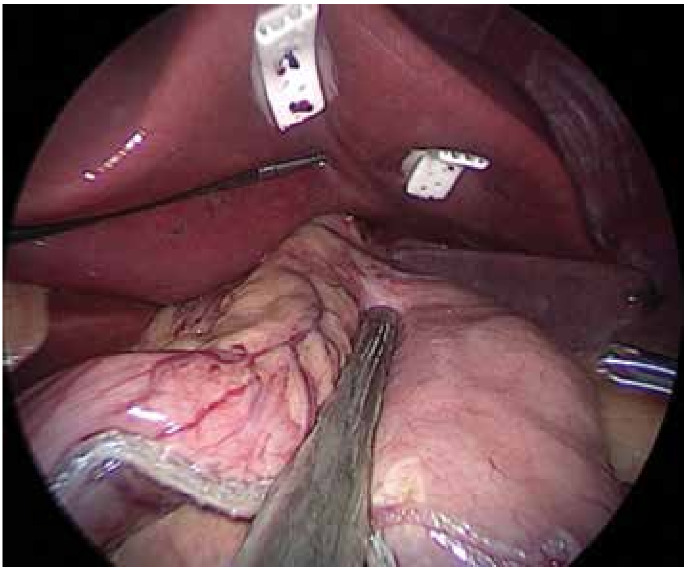

Figure 10. Successive firings of the staple device toward the fundus.

suture line (**Figure 11**). Constant communication with the anesthesiologist is of paramount importance, inserting and withdrawing the orogastric tube before and after application of each stapler to make sure the bougie is not stapled into the remnant stomach. It is also highly recommended to check the posterior aspect of the stomach before each firing of the device in order to avoid twisting and in-folding of tissues. The entire fundus, including its posterior

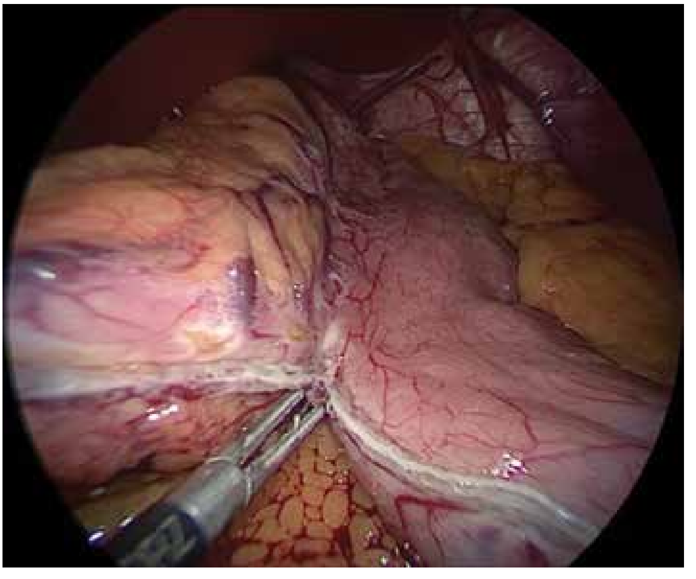

Figure 11. Removal of migratory crotch staples.

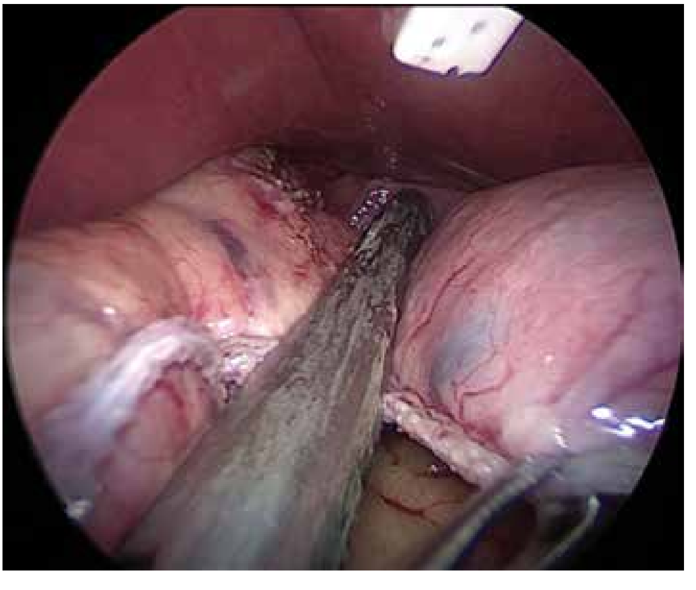

Figure 12. Staple firing 1 cm away from the GE junction.

wall, is to be included in the resected part. Before firing of the last stapler, always verify that the stapler is placed not less than 1 cm from the GE junction and that both tips of the stapler are always in sight (**Figure 12**).

2.3.8. Hemostasis

The entire length of the staple line should be inspected for any bleeding. Bleeding may be controlled using electrocautery, clips or over sewing. No buttressing material is placed over the staple line.

2.3.9. Fixing the tube

One or two fixing stitches are taken between the stapled sleeve and the retroperitoneal fat to prevent rotation of the sleeve tube.

2.3.10. Specimen extraction

The LSTs are removed and the entry and exit points on the liver are cauterized to achieve hemostasis. Specimen is then extracted through the umbilical port and closure of the rectus sheath done with 2-0 Vicryl. Subcutaneous layers of all ports closed with 3-0 Vicryl and skin closed with interrupted subcuticular stitches. Dermabond is applied and dressing done.

2.3.11. Surgical outcomes

The mechanism of action of LSG appears to be by the restriction of the volume of stomach and the removal of ghrelin-producing fundus [3]. The decreased ghrelin leads to early satiety and decreased hunger. Another mechanism is increased gastric emptying which combined with decreased gastric acid secretion causes incomplete digestion [4]. Increased gastric emptying is associated with higher levels of glucagon-like-peptide-1 (GLP-1), a glucose-regulating insulin-enhancing agent, which has been linked to weight loss and resolution of type 2 diabetes mellitus [5].

In a retrospective study, the EWL after 3 and 6 years follow-up of LSG was 72.8 and 57.3%, respectively [4]. Gustavo et al. in their long-term study showed a mean %EBMIL (percentage of excess BMI Loss) of 82.4, 75.9 and 62.5 and % TWL (percentage of total weight loss) of 28.5, 25.8 and 21 at 3, 6 and 11+ years of follow-up, respectively [6].

3. Sleeve-based procedures

One of the arguments against LSG is that its weight loss as well as its efficacy in diabetes remission is inferior and not sustainable compared to RYGB. This is owed to the fact that LSG do not own the content of bowel bypass. Laparoscopic loop duodenojejunal bypass with sleeve gastrectomy (LDJB-SG) and sleeve gastrectomy with proximal jejunal bypass (SG-PJB) are a combination of both a restrictive and malabsorptive procedures (**Figure 13** and **28**). First described by Huang et al. in 2011, LDJB-SG has a lower incidence of dumping syndrome and marginal ulcer, both commonly experienced in RYGB, due to an intact pylorus which acts as

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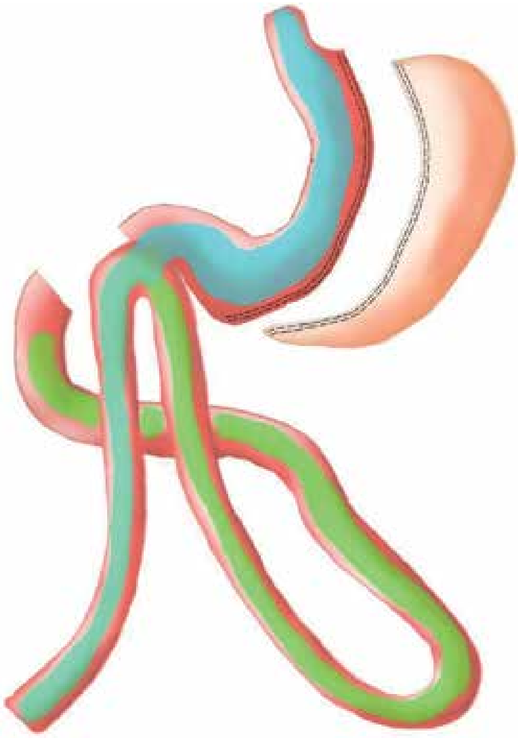

Figure 13. Schematic diagram of LDJB-SG.

a sphincter mechanism and a creates a neutral condition from mixture of gastric acid, pancreatic juice and bile around the duodenojejunal anastomosis [7]. SG-PJB was designed by Alamo et al. in 2005 and later revised in 2009 [9, 10]. Surgical results of weight loss and comorbidity resolution were comparable to Roux-en-Y gastric bypass in his reports. Both LDJB-SG and SGPJB can be an alternative operation that could potentially lessen the complications associated with the conventional gastric bypass.

3.1. Loop DuodenoJejunal Bypass with Sleeve Gastrectomy

3.1.1. Indications and Contraindications

Indication for this procedure includes BMI ≥ 40 kg/m^2 without comorbidities or ≥35 kg/m^2. This can also be offered as a surgical treatment for poorly controlled type 2 diabetes in Asian patients with BMI ≥ 32.5 kg/m^2 without comorbidities or >27.5 kg/m^2 with comorbidities. Contraindications include chronic alcoholism, drug and substance abuse, major psychiatric disorder, severe gastroesophageal reflux disease and chronic duodenal ulcer [8].

3.1.2. Preoperative work up and preparation

Comprehensive preoperative workup for DJB-SG is the same as that of the other bariatric procedures. Patients are admitted the day prior to the procedure were they are started on clear liquid diet. Single dose of prophylactic antibiotic and proton pump inhibitor are given an hour prior to surgery. Low molecular-weight heparin (LMWH) is prescribed to lower the incidence of deep vein thrombosis (DVT) and other thromboembolic events.

3.1.3. Positioning

Patient is positioned flat on the operating table with both upper extremities extended out. Patient is secured at the chest and thighs using straps and a foot board in preparation for a steep reverse Trendelenburg position. The surgeon and the scrub nurse both stand on the patient's right while the first assistant and the cameraman stand on the patient's left.

3.1.4. Operative Technique

3.1.4.1. Port placement

Five-port technique is utilized for this procedure as shown in **Figure 14**. A 12 mm optical port on the left of umbilicus is placed after abdominal cavity is entered using the closed Veress technique or via an optical trocar. One 15 mm port is placed in immediate supraumbilical region and another 12 mm port is placed to the right of umbilicus mirroring the one on the left, both of which serve as the surgeon's right hand working ports. A 5 mm trocar is placed in the right midclavicular line below the costal margin for the surgeon's left hand while another 5 mm trocar is placed in the midclavicular line below the left subcostal margin for the assistant.

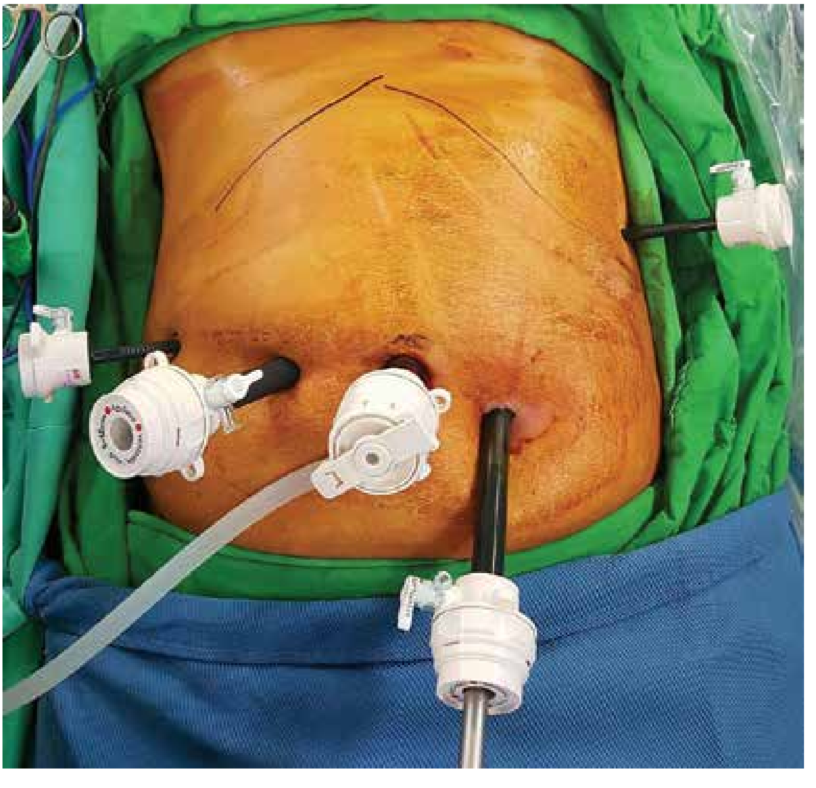

Figure 14. Port placement for LDJB-SG.

3.1.4.2. Placement of liver suspension tape

An LST previously discussed earlier in this chapter is utilized. However, instead of using a 2.5 cm cut JP drain, 5 cm is used for the second tape in order to lift both the lobes of the liver along with the falciform ligament away from the field (**Figure 15**).

3.1.4.3. Sleeve gastrectomy

The formation of the gastric sleeve tube is done in a similar way as described earlier in this chapter.

3.1.4.4. Duodenal transection

Proper exposure of the entire length of the stomach and first part of the duodenum is critical to the success of this procedure. After sleeve gastrectomy has been performed, the next step is to dissect the first part of the duodenum. A counter traction suture is placed at the distal end of the sleeved stomach to visualize the first part of the duodenum (**Figure 16**). At a distance approximately 2 cm distal to the pylorus, a tunnel is created posterior to the duodenal wall and just anterior to the gastroduodenal artery using a combination of a blunt dissector and Flexlap Gold Finger retractor (Flexlap Gold Finger Retractor by Ethicon Endo Surgery, USA) as seen in **Figures 17** and **18**. A tape is then passed in the tunnel behind the duodenum and lifted laterally and downwards to serve as a traction while inserting the endostapler (**Figure 19**). Using a 45 mm curved tip articulating tan reload (EGIA45CTAVM Endo GIA 45 mm Curved Tip articulating vascular/medium reload with Tri-Staple™ Technology), the first part of the duodenum is transected. Care is taken to avoid injury to the common bile duct (CBD), pancreas and major vessels in the area (**Figure 20**) [8].

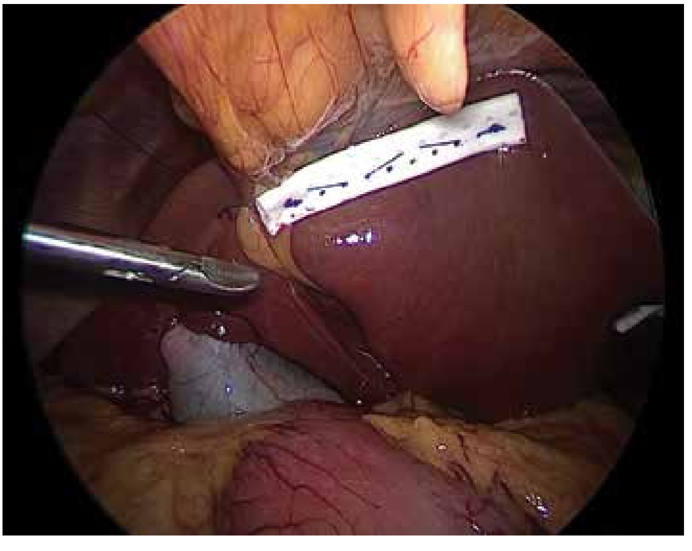

Figure 15. Liver suspension for both lobes.

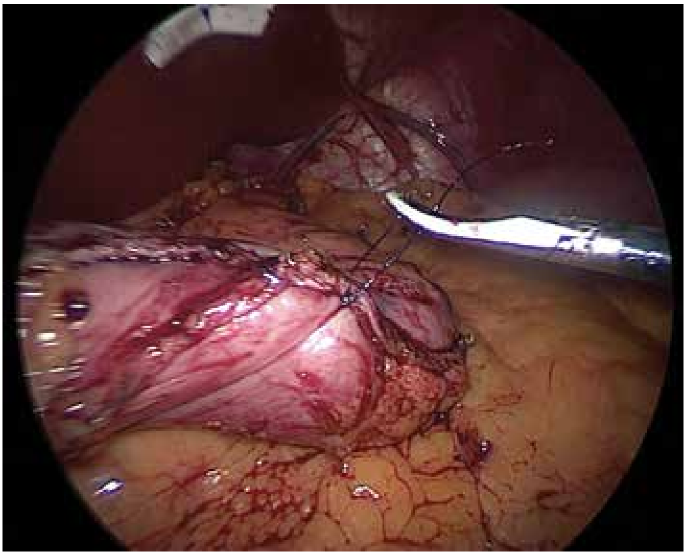

Figure 16. Counter traction suture.

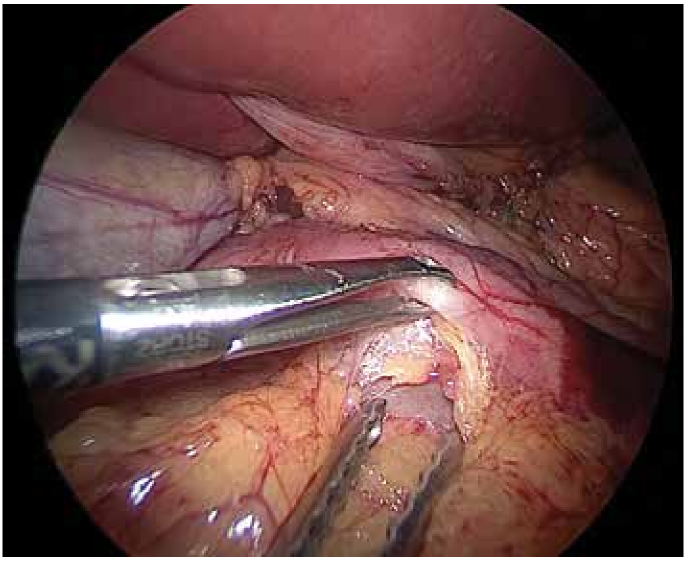

Figure 17. Retroduodenal tunnel.

3.1.4.5. Duodenojejunostomy

The ligament of Treitz is identified as it exits at the root of the transverse mesocolon. A length of jejunum is measured for 200–300 cm starting from the ligament of Treitz. The loop of jejunum is pulled up and a stay suture is placed between the loop of jejunum and pylorus. An enterotomy of 1.5 cm is placed obliquely in the first part of the duodenum and antimesenteric

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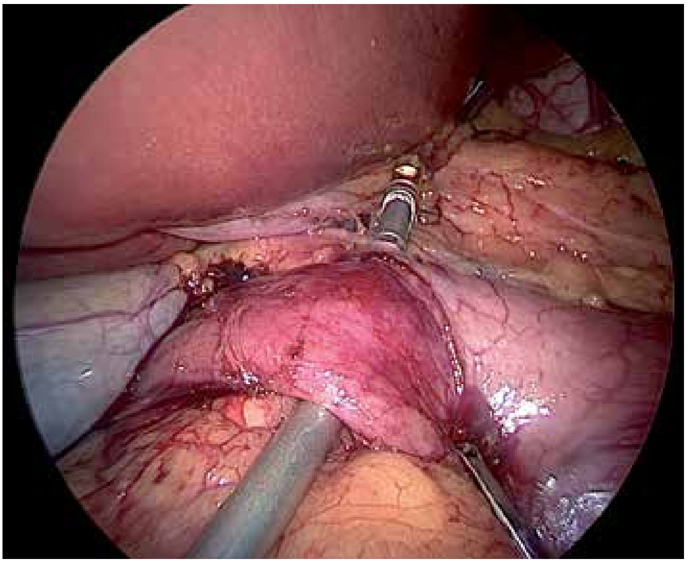

Figure 18. Retroduodenal tunnel passing through the lesser sac using the Goldfinger retractor.

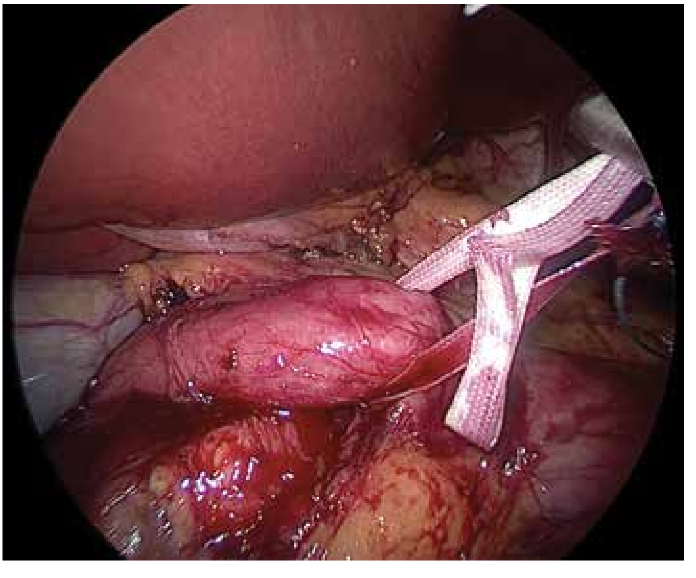

Figure 19. Lifting and retraction of the 1st portion of the duodenum using a tape.

side of jejunum (**Figure 21** and **22**). A completely hand-sewn side to side duodenojejunal anastomosis in a running fashion is created using a 3-0 absorbable glyconate monofilament suture (3-0 B | BRAUN MONOSYN™ UNDYED 28" HR26 TAPER) (**Figures 23–25**). Then an antitorsion suture between antrum and jejunum is placed, around 4 cm proximal to the D-J anastomosis [8].

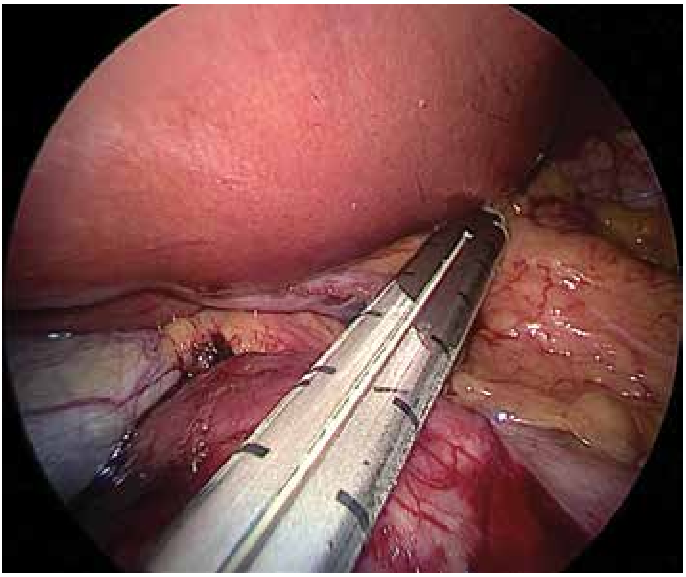

Figure 20. Duodenal transection.

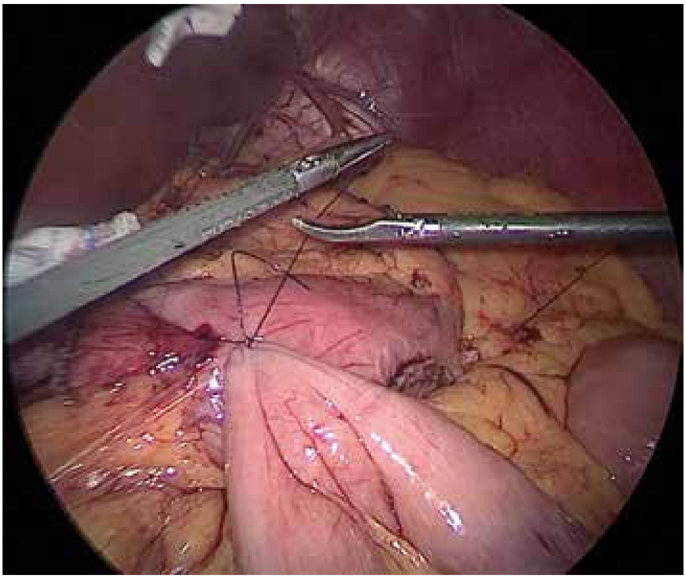

Figure 21. Stay suture between sleeved stomach and jejunum.

3.1.4.6. Closure of mesenteric defect

Peterson's mesenteric defect is closed in a continuous running technique using 2-0 nonabsorbable polyester suture (W6977 Ethibond Excel™ Polyester suture) (**Figure 26**). A Jackson Pratt drain is placed under the entire length of stomach tube and duodenojejunal anastomosis (**Figure 27**).

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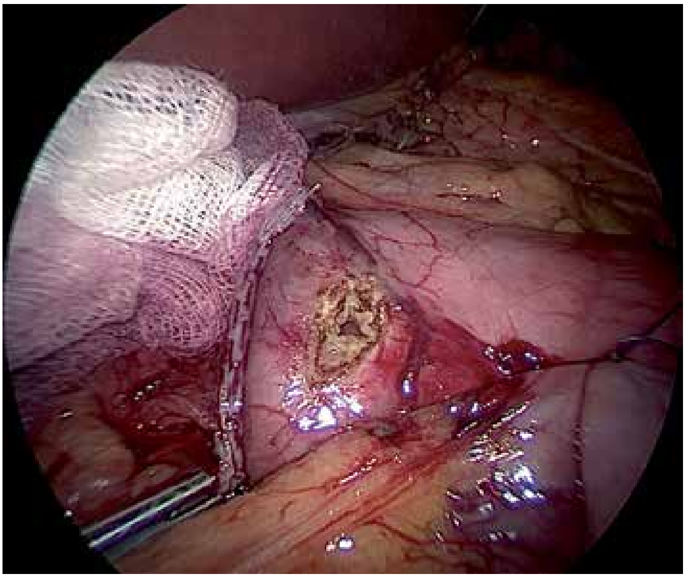

Figure 22. Duodenal enterotomy placed obliquely.

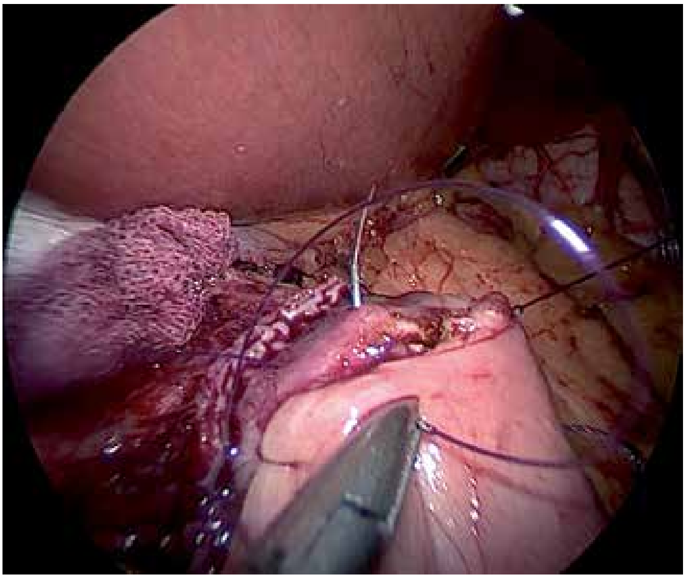

Figure 23. Completely hand-sewn duodenojejunal bypass.

3.1.4.7. Postoperative care and follow-up

Adhering to the early recovery after surgery (ERAS) postoperative protocol, adequate pain control is administered via the intravenous route and early ambulation is encouraged in our patients as early as six hours after surgery in order to avoid pulmonary complications.

Once the patient is fully awake, clear liquid diet as instructed by our dietitian is commenced. Intravenous antibiotic is administered for one more day. Patients are usually discharged 2–3 days after surgery. Patients are placed on bariatric diet as instructed by the dietitian. Proton pump inhibitors are given for 1 month after surgery. Follow-up schedule is as follows: 1 week, 1, 3, 6 and 12 months after surgery. One year after the surgery, patients are advised to follow-up every 6 months thereafter.

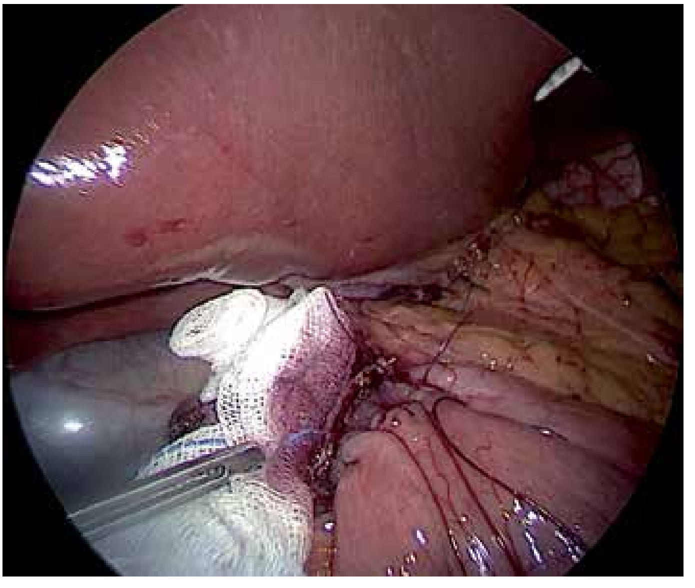

Figure 24. Anterior wall of DJB.

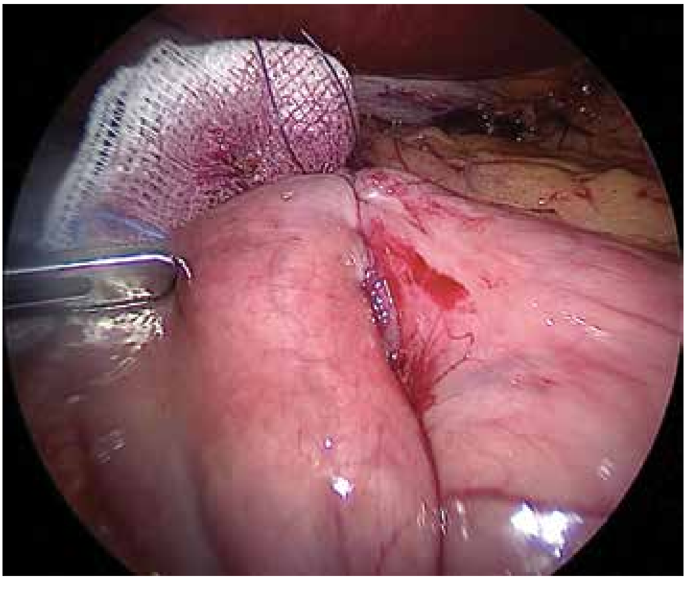

Figure 25. Posterior wall of DJB.

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3.1.5. Surgical Outcomes

The mechanism of weight loss in LDJB-SG is due to the resection of Ghrelin-secreting cells located in the fundus of the stomach. A significant drop in this hormone's level after the procedure causes decrease in sensation of hunger and early satiety. Furthermore, aside from its weight-loss effect, caloric restriction also helps in the improvement of insulin resistance and

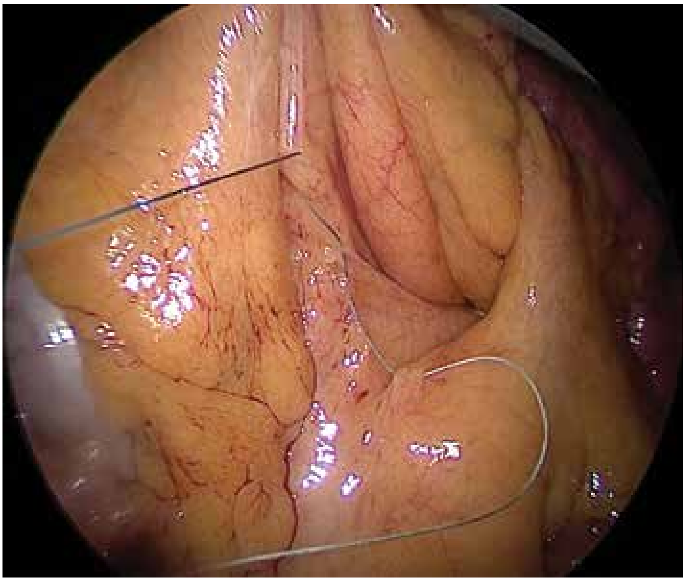

Figure 26. Closure of Petersons defect.

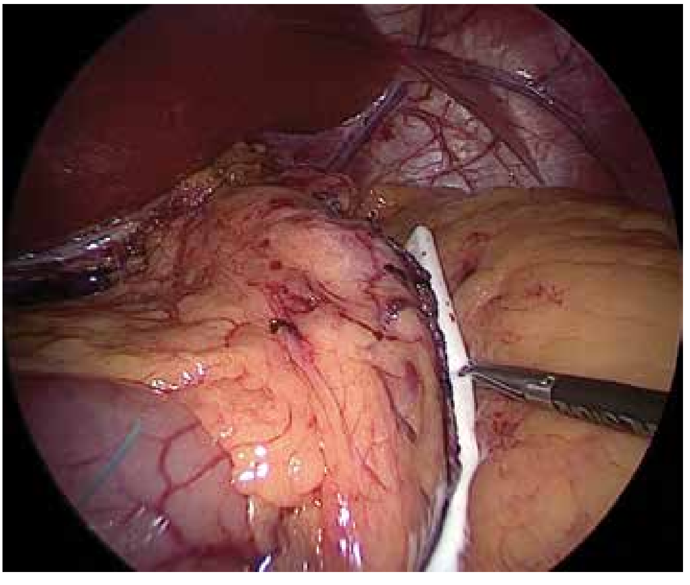

Figure 27. Placement of JP drain along DJB anastomosis and entire length of the sleeve suture line.

increase in glucose tolerance. However, the efficient glycemic control of this procedure is predominantly due to the exclusion of the duodenum (Foregut theory) and the faster delivery of undigested food and more concentrated bile to the distal small bowel (Hindgut theory) which ensures secretion of incretins.

In a prospective study by Huang et al. published in 2013 comparing LDJB-SG with RYGB, LDJB-SG had a superior remission rate of T2DM (60% vs 49%) and a better over-all glycemic control (90% vs 71%) compared to RYGB in patients with BMI ≤ 35 kg/m^2 at 1 year after surgery. Fasting blood sugar levels was also significantly lower in the LDJB-SG group (98.0 ± 18.0 vs 106.0 ± 31.7 mg/dl). The drop in HbA1C was also lower in the LDJB-SG compared to the RYGB (6.0 ± 0.9 vs 6.3 ± 1.2) although this did not attain a statistically significant level (P value = 0.442). Resolution of other obesity-related comorbid factors were also seen in LDJB-SG that was comparable to the RYGB group (Hypertension = 85.7% vs 88.2% and Dyslipidemia = 70% vs 76.6% resolution rates) [8].

In a case-matched study comparing of 30 patients undergoing LDJB-SG and 30 patients undergoing RYGB, the mean BMIs dropped significantly to 22.4 kg/m^2 (±2.4) (range 18.4–27 kg/m^2) and 21.9 kg/m^2 (±2.5) (range 17.7–26.5 kg/m^2) from preoperative values of 28.2 kg/m^2 (±3.6) and 27.8 kg/m^2 (±3.8) at 1 year after surgery ($p < 0.01$). However, no statistical difference was seen between the two groups. HbA1c and fasting glucose were also significantly decreased 1 year after surgery compared to its preoperative value from 8.98 (±1.75%) to 6.52% (±1.03) and 168.3 (±54.9 mg/dL) to 106.5 mg/dL (±28.2 mg/dL). Comparing complete remission of T2DM in 1 year after surgery, the LDJB-SG had a remission rate of 36.6% of patients (11/30) compared to 30% (9/30) in the RYGB group. As far as complications, the rate for early complication favors that of RYGB (1 case vs 4 cases). However, there is a note of a trend toward lower occurrence of late complication rate in LDJB-SG compared to RYGB (5 vs 8 cases, $p < 0.08$) [11].

Lee et al. compared single anastomosis duodenojejunal bypass with sleeve gastrectomy (SADJB-SG) with RYGB and minigastric bypass (MGB). The operation time was significantly longer in SADJB-SG compared to the other types of bypass (181.7 mins vs 160 mins for RYGB vs 120.1 mins for MGB; $p < 0.01$). During the interim follow up period at 1, 3, 6 and 12 months after surgery, the mean BMI dropped to 32.9 ± 4.8, 29.9 ± 6.8, 27.6 ± 5.4 and 25.9 ± 4.6 kg/m^2, respectively. The percentage weight loss during these same follow-up periods were 15.1, 20.3 25 and 32.7%. 12 months after surgery, comparing percent weight loss (% WL) of the three procedures, the results showed a higher percent weight loss for SADJB-SG (32.7 ± 7.9% SADJB-SG vs 28.9 ± 9.0% MGB vs 26.1 ± 4.1% RYGB). Results also showed a superior percent excess weight loss for SADJB-SG (80.3 ± 24.8%) compared to the two bypass procedures (68.6 ± 58.2% MGB and 63.4 ± 31.8% RYGB). In the same report, T2DM was seen in > 80% of the subjects with a preoperative mean HbA1c level of 9.2%. This value decreased to 6.1% 1 year after surgery with a complete remission rate of T2DM in 64% of the patients [12].

In an attempt to evaluate the role of duodenal exclusion in glycemic control, a matched group study comparing LDJB-SG and SG alone was done. At 1 year after surgery, the LDJB-SG (26 patients) presented with a higher percent excess weight loss (87.2 ± 14.9% vs 67 ± 27.0%; $p = 0.23$) and a lower BMI (23.9 ± 2.2 vs 26.1 ± 3.7; $p = 0.065$) compared to the SG alone group (29 patients). As far as T2DM remission rate is concerned, the LDJB-SG had a 92.3% total glycemic control rate compared to 86.2% in the SG alone group. The mean reduction in the HbA1c level for the LDJB-SG was likewise higher compared to the SG group (2.8 vs 2.1% p = 0.45) [13].

3.2. Sleeve gastrectomy with proximal jejunal bypass (Figure 28)

3.2.1. Indication and contraindication

The indications and contraindications of PJB-SG are the same as that of the conventional stand-alone sleeve gastrectomy. Furthermore, this can also be offered as a metabolic surgery for patients with BMI between 27.5 and 35 with type 2 Diabets.

Figure 28. Schematic diagram of LPJB-SG.

3.2.2. Preoperative workup and preparation

Like in all bariatric procedures, a complete preoperative workup should be done in order to select appropriate candidates for the procedure. All patients are evaluated by a multidisciplinary team dedicated in bariatric surgery including a bariatric surgeon, bariatric physician, gastroenterologist, anesthesiologist, psychiatrist, nutritionist and fitness coach. Other specialists may be called upon if required.

3.2.3. Positioning

Patient is positioned supine with upper extremities abducted and lower extremities adducted. Patient is then secured to the operating table using straps and foot boards. Patient is placed in steep reverse Trendelenburg position.

3.2.4. Operative technique

3.2.4.1. Port placement

A 4-port technique is utilized with the surgeon positioned on the patient's right side and the assistant and camera man standing on the patient's left. Port placement is similar to LSG with an assistant port in left anterior axillary line below the costal margin (**Figure 29**).

3.2.4.2. Pneumoperitoneum

Pneumoperitoneum is accomplished either via Veress technique or through a 12 mm optical trocar using a 30-degree scope in the left periumbilical area.

3.2.4.3. Placement of liver suspension tape

Liver retraction is done using the LST similarly placed as in the standard LSG technique. Alternatively, a Nathanson liver retractor can also be used.

3.2.4.4. Sleeve gastrectomy

Standard sleeve gastrectomy is performed as previously described earlier in this chapter.

3.2.4.5. Proximal jejunal bypass

After completing the sleeve gastrectomy, ligament of Treitz is identified. Transection of the jejunum is done at 20 cm from the ligament of Treitz using either a 45 mm white cartridge reload (EGIA45AMT Endo GIA™ 45 mm articulating medium/thick reload with Tri-Staple Technology) or a 45 mm white cartridge reload (ECR45W Echelon Endopath™ tri-stapler reload cartridges by Ethicon). Next 300 cm of small bowel is measured distally and a side-to-side jejunojejunal anastomosis was fashioned out using the same cartridge and stapling device. The jejunojejunostomy is created with hand-sewn technique using 3-0 Absorbable Glyconate Monofilament running suture (3-0 B | BRAUN MONOSYN™ UNDYED 28" HR26 TAPER) (**Figures 30–32**).

3.2.4.6. Closure of mesenteric defect

The mesenteric defect is closed with simple running sutures using 2-0 nonabsorbable polyester suture (Ethibond Excel™ polyester suture). No drain is placed.

Figure 29. LPJB-SG port placement.

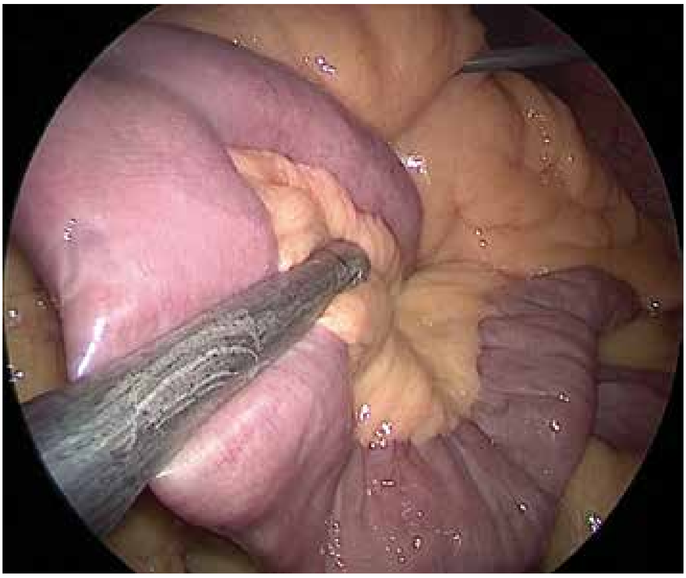

Figure 30. Transection of Bilio-pancreatic limb 20 cm from ligament of Treitz.

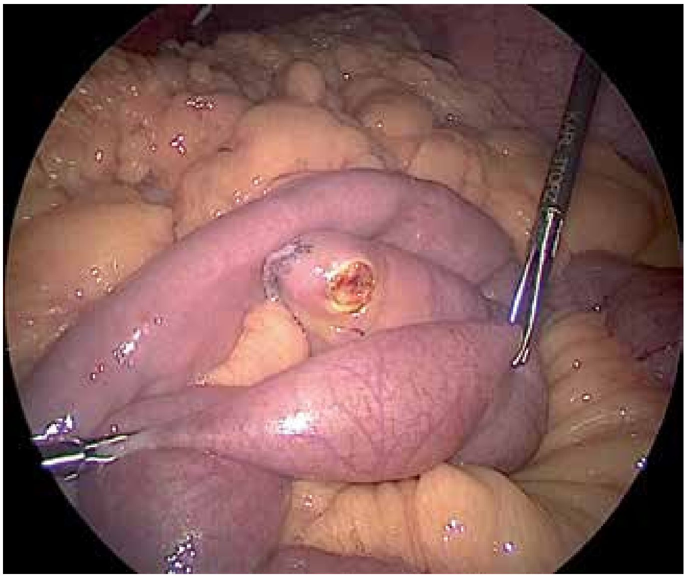

Figure 31. 300 cm bypassed proximal jejunum.

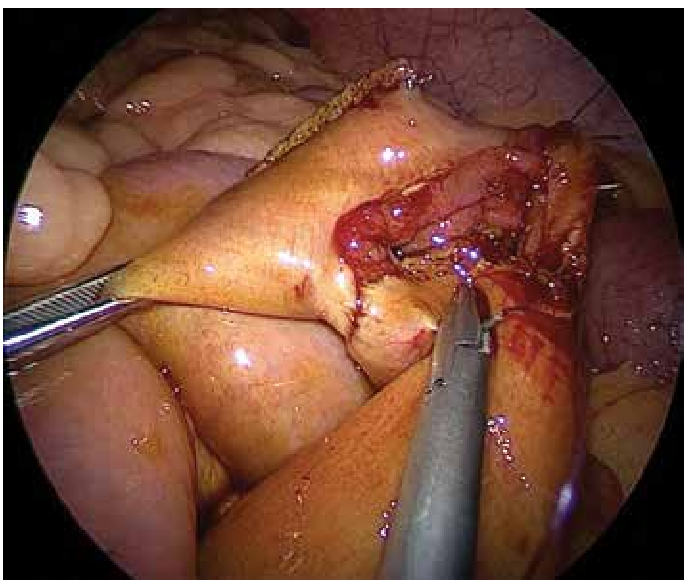

Figure 32. Closure of jejunojejunal anastomosis.

3.2.4.7. Gastric sleeve fixation

The suture line of the sleeved stomach is anchored with one or two stitches at the retroperitoneal fat using 3-0 Polyglactin 910 multifilament absorbable suture (J774D Ethicon 3-0 Coated Vicryl™ Taper SH). This prevents inadvertent twisting of the tubularized stomach (**Figure 33**).

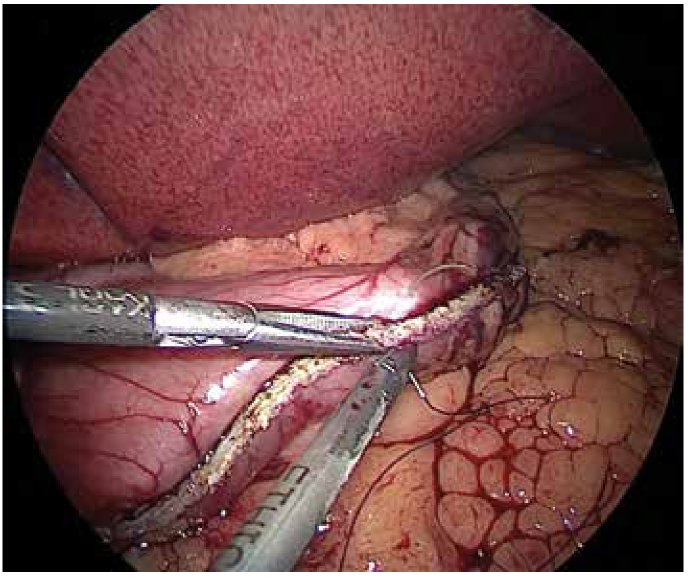

Figure 33. Anti torsion stitch.

3.2.5. Surgical Outcomes

Factors that contribute to the magnitude of weight loss and diabetic remission in sleeve-based procedures are still not fully elucidated. It probably owes its weight loss capabilities by eliminating the function of the stomach as a reservoir hereby reducing caloric content of processed food. Furthermore, because of the jejunojejunal bypass, the terminal ileum is exposed much earlier to undigested food and a more concentrated bile, both of which stimulate the release of incretins, primarily glucagon-like peptide 1 (GLP-1).

In the original study of Alamo et al., the average BMI and average weight at 12 months after vertical isolated gastroplasty with gastroenteral bypass were 23.4 ± 3.3 kg/m^2 (19.2–27.7) and 65.1 ± 15 kg (46–83) from 41.2 ± 5.1 kg/m^2 (35.3–57.8) and 110.7 ± 16.2 kg. The mean percent excess weight loss (% EWL) was 90.2 ± 11.9% [3]. In other studies, the mean BMI was reduced to 21.4 ± 1.9 kg/m^2 at 18 months' follow-up from 31.6 ± 2.1 kg/m^2 with a mean percent EWL of 75.7 ± 8.5%. Comparing these figures with RYGB, in the study by Higa et al., where patients were followed-up for 10 years, the mean percent excess weight loss was 57% and the average postoperative BMI was 33 ± 8.0 kg/m^2 at 10 years [14].

In a cohort study of 49 patients (2012) evaluating the efficacy of SGPJB in ameliorating T2DM in patients with BMI < 35 kg/m^2, 81.6% (40/48) of patients with T2DM achieved complete remission after SGPJB with the remaining nine patients achieving improvement. As far as discontinuation of oral hyperglycemic agents and insulin dependence are concerned, 97.6% (40/41) of patients stopped taking their medications and 100% (8/8) stopped using insulin [10].

4. Laparoscopic Roux-En-Y Gastric Bypass (Figure 34)

Mason observed that distal gastrectomy with Billroth II reconstruction causes weight loss. The first open RYGB was performed for weight loss in 1967 while the first Laparoscopic RYGB was performed by Wittgrove [15]. Since then, laparoscopic RYGB is one of the most commonly performed bariatric procedure done for excess weight loss (**Figure 34**).

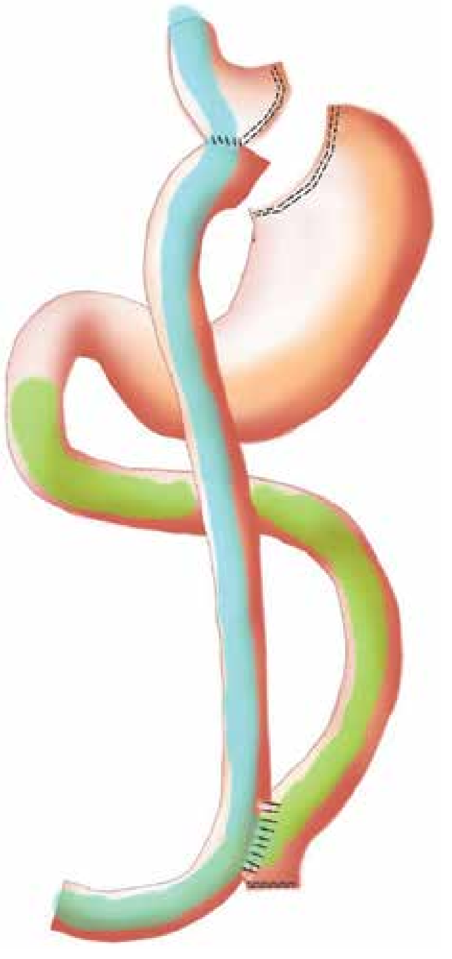

Figure 34. Schematic diagram of LRYGB.

Based on the 1991 NIH criteria, there are a number of widely accepted indication and contra-indication which make a patient suitable for Bariatric or weight loss surgery:

- BMI > 40 without comorbidities.
- >35 with associated obesity-related illness such as diabetes or sleep apnea.
- Failed reasonable attempts at other weight loss techniques.

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- Obesity-related health problems.
- No psychiatric or drug dependency problems.
- A capacity to understand the risks and commitment associated with surgery.
- Pregnancy not anticipated in the first 2 years following surgery.

For Asians, BMI is reduced by 2.5 for the above.

4.1. Operative technique

4.1.1. General preparations

Preoperative investigation includes standard basic blood profile, thyroid function test, serum cortisol level, HbA1c and C-peptide if diabetic, whole abdominal ultrasound and upper gastrointestinal endoscopy. Patient will be placed on NPO and started with intravenous drip 125–150 ml/h. Anticoagulants are usually not needed but thromboelastic stockings are applied.

4.1.2. Patient positioning

Patient is positioned supine with both arms stretched out. Surgeon will be on the right side of the patient while the assistant surgeon and camera holder will be on the left. The assisting nurse will stand on the same side as the surgeon. Monitor(s) are placed at the head end of patient.

4.1.3. Port placement

A 12 mm optical port placed 3-finger breadth left lateral to umbilicus. A 5 mm port is placed 4-finger breadth to the right of umbilicus for surgeons left hand working port. A 12 mm port is placed at 45 degrees to right hand port in the right mid clavicular line for surgeon's left hand and stapler insertion. Another 5 mm port is inserted in upper left subcostal region in the anterior axillary line for assistant surgeon (**Figure 35**).

4.1.4. Liver suspension tape

Liver retraction is done with liver suspension tape using a straight needle prolene suture-Jackson Pratt drain as previously described in this chapter for LSG.

4.1.5. Creation of gastric pouch

Gastric pouch is created by marking with orogastric calibration tube (OGCT) balloon with 25 ml insufflation. Perigastric dissection is done with hook diathermy at lesser curve with preservation of hepatic branch of vagus nerve, usually after the first vascular branch. Two-three staplers (medium thickness) are used to create the gastric pouch. The final pouch size would be about 15–20 ml. Adhesion on the posterior aspect of gastric pouch are cleared. A small gastrostomy is created at the posterior side of the pouch with hook diathermy for the creation of gastrojejunostomy (**Figures 36–42**).

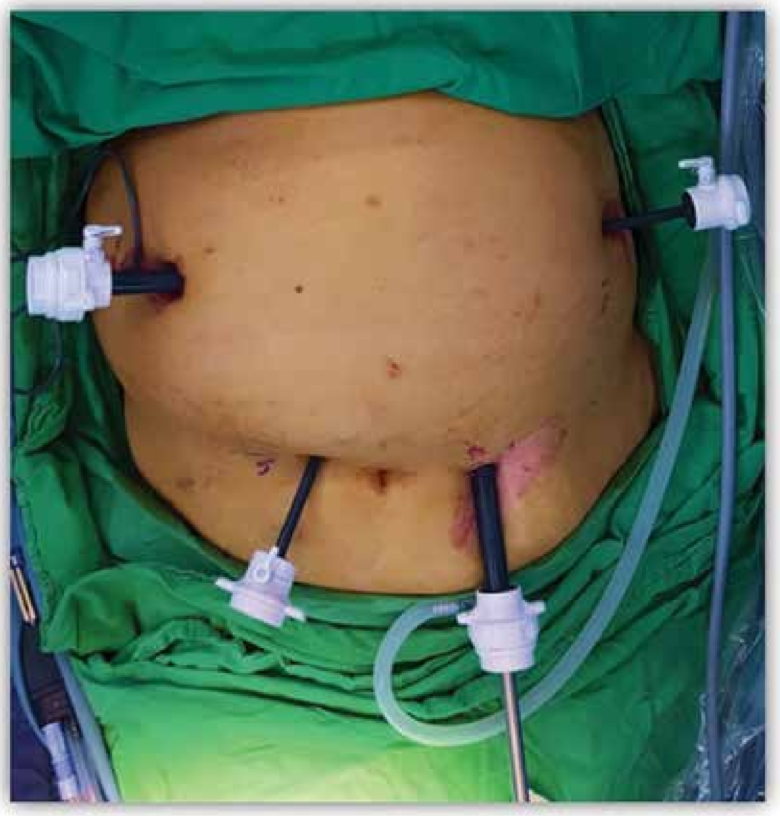

Figure 35. Port placement.

4.1.6. Gastrojejunostomy

Ligament of Treitz is identified and 100 cm of proximal jejunum is measured. Jejunotomy is created with hook cautery and loop of jejunum is anastomosed to the gastric pouch with linear stapler. Diameter of the gastrojejunal stoma is about 1.5–2 cm. Jejunum is disconnected just proximal to gastrojejunostomy with a 45 mm white cartridge reload (EGIA45AMT Endo GIA™ 45 mm articulating thin reload with Tri-Staple Technology or ECR45W Echelon Endopath™ tri-stapler reload cartridges by Ethicon) to avoid creating a "candy cane" blind loop. Closure of gastrojejunal enterotomy is performed with Monocryl 3-0. 38 Fr orogastric tube is passed through the gastrojejunal anastomosis to check for patency (**Figures 43–46**).

4.1.7. Jejunojejunostomy

Jejunum is measured for a distance of 100 cm from gastrojejunostomy and side to side jejunojejunostomy is created with 45 mm cartridge (EGIA45AMT Endo GIA™ 45 mm articulating thin reload with Tri-Staple Technology or ECR45W Echelon Endopath™ tri-stapler reload cartridges by Ethicon). Closure of jejunojejunal enterotomy is done with 3-0 Monocryl (**Figures 47** and **48**).

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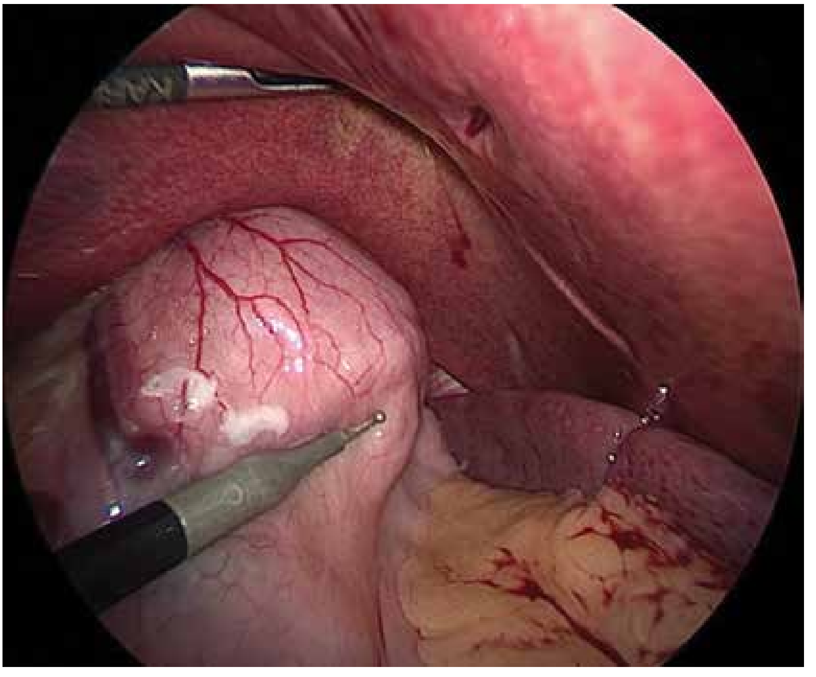

Figure 36. Calibration of gastric pouch.

Figure 37. Perigastric dissection.

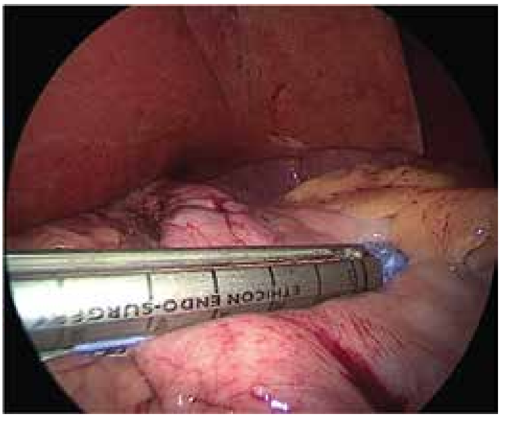

Figure 38. Firing of first staple.

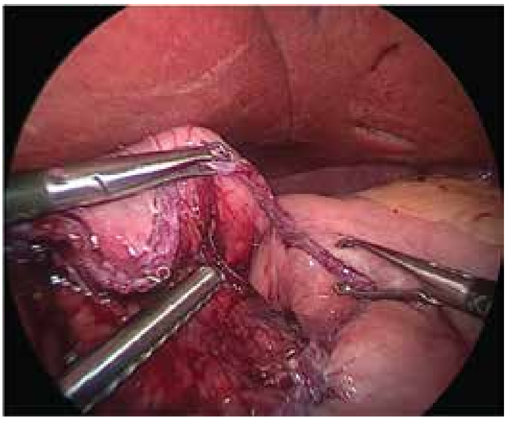

Figure 39. Dissection of adhesions at posterior gastric pouch.

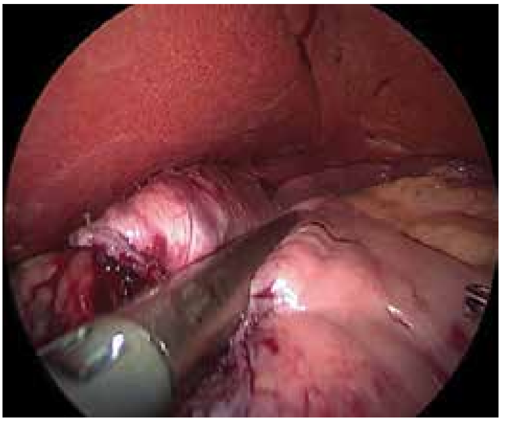

Figure 40. Firing of the 2nd stapler toward the angle of His.

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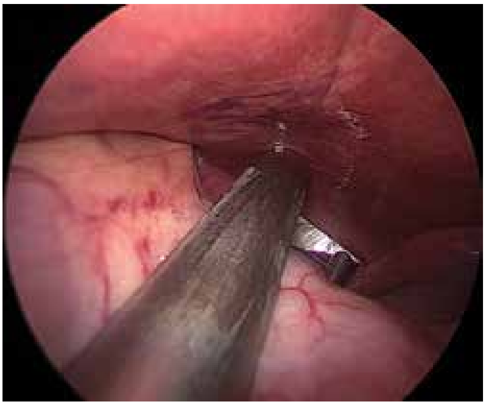

Figure 41. Firing of last stapler 1 cm away from GE junction.

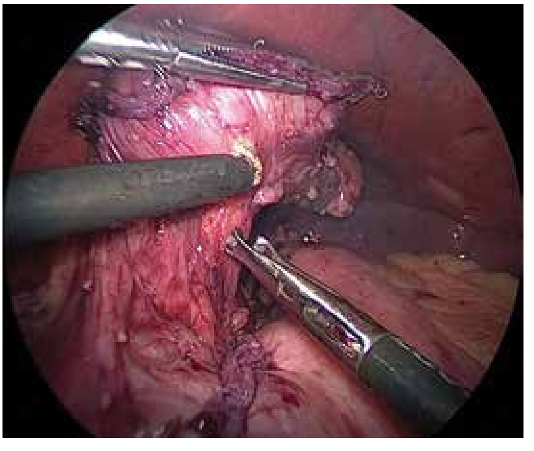

Figure 42. Creation of 1.5–2 cm gastrotomy.

Figure 43. BP limb measuring 100–250 cm from the ligament of Treitz.

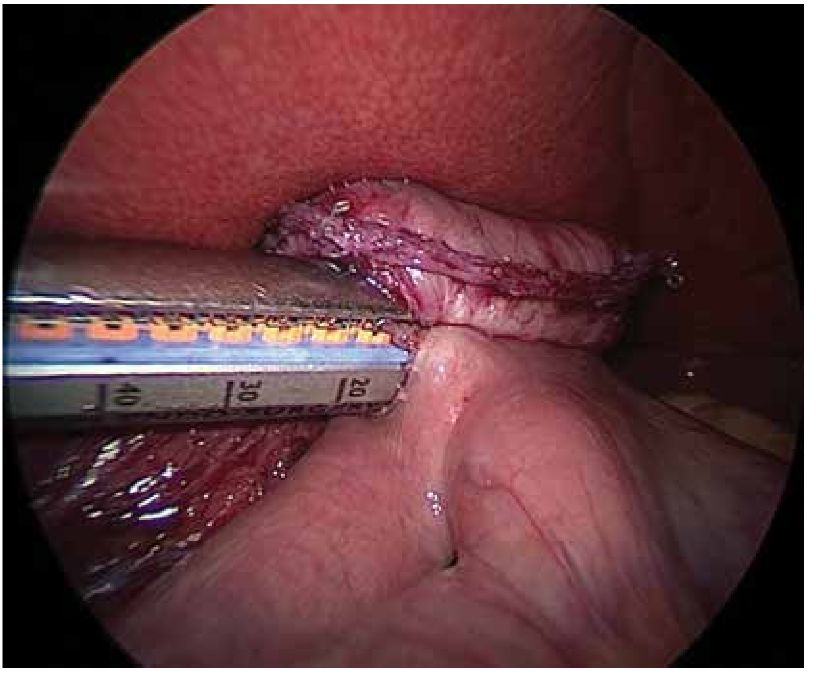

Figure 44. 1.5–2 cm side to side gastrojejunostomy.

Figure 45. Transection of jejunum proximal to GJ anastomosis with thin stapler as close to GJ anastomosis as possible to avoid creating a candy cane stick blind loop.

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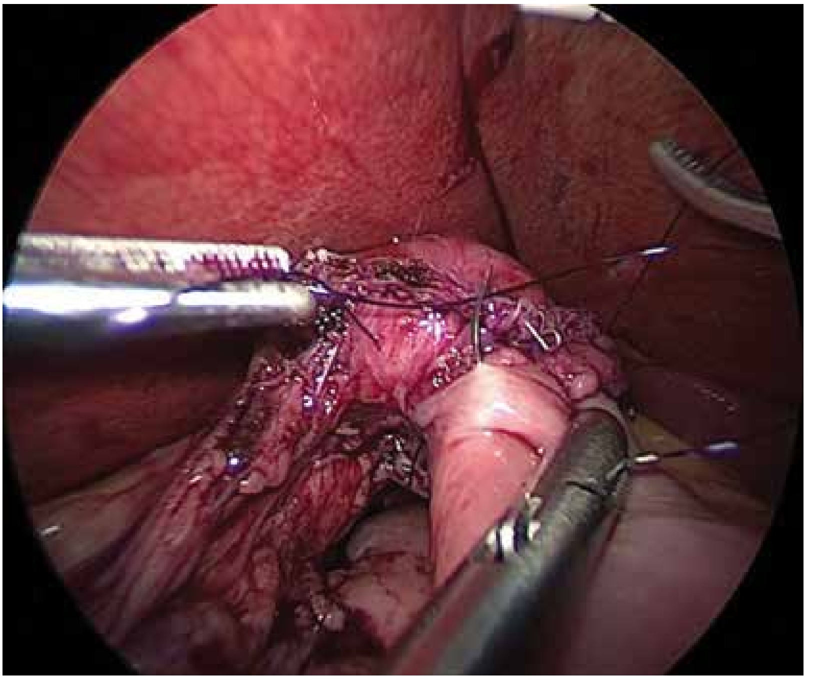

Figure 46. Gastrojejunal anastomosis completed by closure with single layer continuous suture using MONOSYN 3-0 round body needle.

Figure 47. Side to side jejunojejunostomy.

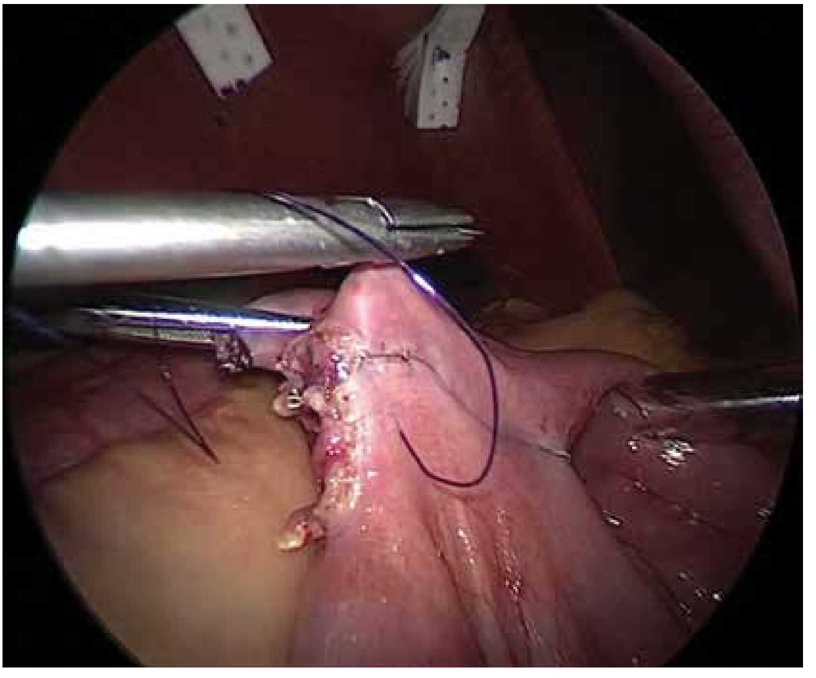

Figure 48. Hand-sewn closure of jejunojejunal anastomosis completed with single layer continuous suture using MONOSYN 3-0 round body needle.

4.1.8. Closure of mesenteric defects

Closure of mesenteric defects is performed with nonabsorbable sutures at jejunojejunal mesentery and Peterson defect (jejunotransverse mesocolon) to prevent internal herniation.

4.1.9. Removal of liver suspension, hemostasis, deflation and closure

After ensuring hemostasis at staple lines and anastomosis, liver suspension tapes are removed and hemostasis of liver punctures is done with diathermy.

4.2. Surgical outcome

4.2.1. Excess weight loss

Weight loss after bariatric surgery is dramatically seen in the first 12 months after surgery and continues at a slower rate up to 18 months postoperation. Excess weight loss after gastric bypass is between 72 and 82% within 12 months after surgery [16–18].

4.2.2. Improvement of comorbidities

Gastric bypass resulted in marked improvement in the biochemical markers of diabetes. Type 2 Diabetes Mellitus resolution is as high as 90.9% with mean fasting glucose reduction from 204 to 103 mg/dl, mean HbA1c reduction from 9.2 to 5.9% without T2DM medication in 12 months follow up. Up to 90% of patient did not need medication for control of glycaemia post operatively [19].

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Gastric bypass can achieve a dramatic improvement of nonalcoholic fatty liver disease (NAFLD) both biochemically and histologically in morbid obesity [20]. Likewise, with significant weight loss and reduction of BMI after gastric bypass, pulmonary function improved in obese patients, which are correlated with decrease in waist circumference and possibly intra-abdominal pressure [21].

4.2.3. Complications

Complications occur in up to 20% patients and include anastomotic leak (0.25%), acute and late gastrojejuntostomy stricture (5%), gastrojejunostomy hemorrhage (1.5%), acute and late jejunojejunostomy stricture (1.5%), iron deficiency anemia, marginal ulcers hemorrhage (1.5%), gastric pouch dilatation (1.5%), nonspecific abdominal pain, hair loss, internal herniation if mesenteric defects are not closed and rarely peroneal nerve palsy, acute cholecystitis, biliary stone with obstruction and cholangitis and intra-abdominal abscess [16–18].

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Chapter 3

Laparoscopic Pancreas Surgery: Image Guidance Solutions

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Erlend F. Hofstad, Ronald Mårvik and
Francisco M. Sánchez-Margallo

Additional information is available at the end of the chapter

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Abstract

Pancreatic ductal adenocarcinoma (PDA) is the fourth leading cause of cancer-related deaths. Surgery is the only viable treatment, but irradical resection rates are still high. Laparoscopic pancreatic surgery has some technical limitations for surgeons and tumor identification may be challenging. Image-guided techniques provide intraoperative margin assessment and visualization methods, which may be advantageous in guiding the surgeon to achieve curative resections and therefore improve the surgical outcomes. In this chapter, current available laparoscopic surgical approaches and image-guided techniques for pancreatic surgery are reviewed. Surgical outcomes of pancreaticoduodenectomy and distal pancreatectomy performed by laparoscopy, laparoendoscopic single-site surgery (LESS), and robotic surgery are included and analyzed. Besides, image-guided techniques such as intraoperative near-infrared fluorescence imaging and surgical navigation are presented as emerging techniques. Results show that minimally invasive procedures reported a reduction of blood loss, reduced length of hospital stay, and positive resection margins, as well as an improvement in spleen-preserving rates, when compared to open surgery. Studies reported that fluorescence-guided pancreatic surgery might be beneficial in cases where the pancreatic anatomy is difficult to identify. The first approach of a surgical navigation system for guidance during pancreatic resection procedures is presented, combining preoperative images (CT and MRI) with intraoperative laparoscopic ultrasound imaging.

Keywords: pancreatic cancer, laparoendoscopic single-site surgery, robotic surgery, image-guided surgery, surgical navigation, near-infrared fluorescence

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1. Introduction

Cancer is the second leading cause of death worldwide after heart disease, with 14.9 million cases and 8.2 million deaths in 2013 [1, 2] and the first leading cause of death among adults aged 40–79 years [3, 4]. Worldwide, pancreatic ductal adenocarcinoma (PDA) is the fourth leading cause of cancer-related deaths [2, 3]. The incidence of all types of pancreatic cancer ranges from 1 to 10 cases per 100,000 people and is generally higher in developed countries and among men [1, 2]. This has remained stable for the past 30 years relative to the incidence of other common solid tumors [5]. Each year about 233,000 new cases of pancreatic cancer are diagnosed worldwide [2, 3]. In the United States, the American Cancer Association expected about 48,960 (24,840 men and 24,120 women) cases of incidence in pancreatic cancer in 2015, with a mortality rate of 83% [6]. In Europe, the estimated number of new cases of pancreatic cancer in 2012 was 79,331 and the estimated number of cases of deaths was 78,669 [7, 8], which is almost the double than in the United States. The 5-year survival rate in the world for pancreatic cancer is still very low, with only 6%. In addition, the overall 2-year survival rate is less than 10%, which has hardly improved over the past two decades [3–5]. In fact, in contrast to the stable or declining trends for most cancer types in the United States, a trend analysis for 2001–2010 indicated that death rates are rising for pancreatic cancer [3, 4].

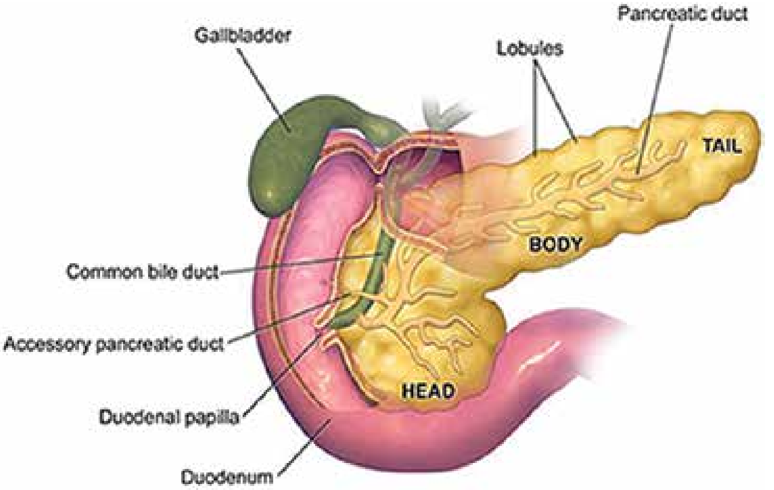

Figure 1. Anatomy of the pancreas. *Source:* "Blausen Gallery 2014". Wikiversity Journal of Medicine. DOI: 10.15347/wjm/2014.010. ISSN 20018762.

Pancreatic tumors are mainly classified as exocrine and endocrine tumors, also known as pancreatic neuroendocrine tumors (NETs). Exocrine tumors are approximately 99% of all primary pancreatic tumors [9] and are divided into ductal adenocarcinomas (80–90% of exocrine tumors), cystic neoplasms, and solid pseudopapillary neoplasms [5, 6, 10]. Ductal adenocarcinomas usually begin in the ducts of the pancreas and are located in the head of the pancreas (60–70%) (**Figure 1**) [10]. Approximately 5–10% of PDA cases are believed to be due

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to hereditary conditions, such as hereditary pancreatitis, Gardner syndrome, familial colon cancer, and others [11].

Pancreatic cases are usually diagnosed at an advanced stage but with few treatment options available. This is attributed primarily to a lack of reliable methods for early diagnosis and rapid metastasis of pancreatic cancer [12]. At the time of diagnosis, less than 20% of patients with pancreatic cancer present with localized, potentially curable tumors [13, 14]. Approximately, 30% of patients receive a diagnosis of advanced loco-regional disease. In addition, 30% of patients have local recurrence of tumors after treatment for an early disease [14].

Although there are several available treatments for pancreatic cancer such as ablative techniques, radiation therapies, and chemotherapy, surgery is the only viable treatment. However, only 10–20% of pancreatic tumors are candidates to be surgically resected at diagnosis [10, 15]. The required surgical intervention for pancreatic cancer treatment depends on the location of tumors. Cancers arising in the head of the pancreas require a pancreaticoduodenectomy (Whipple operation), while those in the tail require a distal pancreatectomy with or without splenectomy [16]. Lesions located in the neck and body may require a distal pancreatectomy, pancreaticoduodenectomy or, rarely, a total pancreatectomy. After surgery, patients with no positive resection margins (R0) have the most favorable prognosis [17]. The median survival length reported for resected (R0) pancreatic cancer ranges from 17–27 months and, after a R1 resection, the average survival length is 10.3 months [18]. However, irradical resection of pancreatic cancers still occurs in 35–42% of patients [16, 19]. This survival time is longer in patients with malignant disease localized to the pancreas and less than 3 cm in diameter than in patients with tumors of greater size or with retroperitoneal invasion (6–15 months) [13]. Other factors, such as tumor size, lymph node status, tumor grade and blood vessel invasion, are also correlated with prognosis [20].

The introduction of minimally invasive surgical techniques in the treatment of pancreatic cancer has allowed almost any pancreatic tumor to be operated by laparoscopic or robotic approaches with similar outcomes to the standard approach [21, 22]. Even new approaches such as laparosendoscopic single-site surgery (LESS) are being applied recently in the field of pancreatic surgery [23, 24]. However, there are some limitations that have hindered the wide use of minimally invasive pancreatic surgery, mainly due to the challenges of these kinds of interventions. The retroperitoneal location of the pancreas makes it difficult to reach during surgery. In addition, this glandular organ presents a delicate structure close to major vascular structures. There are also some technical limitations related to minimally invasive surgery (MIS) such as the lack of visual and tactile information. Increasing the capability to visualize tumor margins or to identify small metastatic nodules may significantly improve the surgical procedure to prevent positive resection margins, and therefore, surgical outcomes [25]. Image-guided techniques can provide intraoperative margin assessment and visualization methods, which may be advantageous in guiding the surgeon to achieve curative resections. Some of these emerging modalities are intraoperative near-infrared fluorescence imaging and surgical navigation systems [26, 27]. However, despite the high rate of positive resections in pancreatic surgery, there is limited medical literature regarding the use of navigation systems as a support during pancreatic interventions. In this chapter, the current laparoscopic surgical techniques and image-guided methods for pancreatic surgery and their associate surgical outcomes will be reviewed.

2. Laparoscopic techniques for pancreatic surgery

Pancreatic cancer is a complex disease, whose optimal treatment depends heavily on careful accurate staging [28]. Surgical resection is still the only potentially curative therapy for pancreatic cancer. However, pancreatic resection is technically challenging and a complex surgical procedure. In this section, the current laparoscopic surgical techniques for pancreatic surgery and their associated surgical outcomes will be reviewed. In order to reach more representative information, only studies published after 2010 and with more than 50 patients included, were taken into account. No limitation in the number of patients was set for the studies using LESS.

2.1. Laparoscopic surgery

2.1.1. Laparoscopic pancreaticoduodenectomy

The first laparoscopic pancreaticoduodenectomy (LPD) was published by Gagner and Pomp in 1994 [29]. They concluded that, although technically feasible, this approach did not confer significant benefit over the conventional open approach in terms of postoperative outcomes or reduced postoperative recovery period. One of the largest barriers of this complex procedure is the reconstruction phase due to the three separate anastomoses to be performed (pancreaticojejunostomy, hepaticojejunostomy, and gastrojejunostomy).

	N	Conv. (%)	Time (min)	EBL (ml)	LHS (days)	Morb. (%)	Mort. (%)	PF (%)	LN (%)	R0 (%)
[30]	53	17	541	195	8	77.3	5.7	13.2	44.2	94.9
[31]	384				10		5.2		4.7	80
[32]	983						5. 1			
[33]	108		379.4	492.4	6					
[34]	65	4.6	368	240	7	40	1.5	16.9	23.1	89
[35]	105	4.7	487.3		15	25	0.9	5.7	12.4	100
[36]	96	3.1					0	28.1		
[37]	75	13.3	551		7	31		9.3		
[38]	137		480.4	592	14.1					
[39]	681				9	39.4	3.8			

N: number of patients; Conv.: conversions; EBL: estimated blood loss; LHS: length of hospital stay; Morb.: morbidity rate; Mort.: mortality rate; PF: pancreatic fistulas; LN: lymph nodes; R0: R0 resection rate.

Table 1. Reported outcomes in laparoscopic pancreaticoduodenectomy.

A summary of the outcomes reported for LPDs are presented in **Table 1**. The average operation time was 486.7 min (range 368–551 min), 8.5% (range 3–17%) conversions, 342.3 ml (range 195–

592 ml) blood loss, 8.9 days (range 6–15 days) hospital stay, 32% (range 25–40%) morbidity, 2.6% (range 0–5%) mortality, 14.7% (range 6–28%) pancreatic fistulas, 21.1% (range 6–28%) harvested lymph nodes, and 89.7% (range 80–100%) R0 resection. The highest rate of conversions reported was due to suspected portal vein involvement [30]. Regarding morbidity rates, the highest rate was caused mainly by surgical site infection, postoperative pancreatic fistula, and intraabdominal access [30]. Myocardial infarctions and positive margins were the main mortality causes [30, 31]. Comparing these results with the conventional open approach [16], LPD leads to an increase in operating time, rate of pancreatic fistulas, and R0 resections; a decrease in estimated blood loss and harvested lymph nodes; and similar results in length of hospital stay, morbidity, and mortality rates.

Most of the studies reported longer operation times using the laparoscopic approach compared to the open approach [30, 35, 37]. Although some studies reported comparable outcomes between open and LPD [30], in general, reduction of blood loss and hospital stay [33, 34] are shown for LPD. In some studies, LPD was associated with equivalent overall hospital cost compared with open pancreaticoduodenectomy [37, 39]. While operating time and supply costs were higher for LPD, it was balanced by reduced cost due to the shorter postoperative hospital stay. A steep learning curve is another aspect associated with LDP and some researchers stated that this procedure should be performed in centers by surgeons with substantial knowledge, experience, and skills [34, 36].

2.1.2. Laparoscopic distal pancreatectomy

Laparoscopic distal pancreatectomy (LDP) was first reported in 1996 by Gagner and Cuschieri [40, 41]. During this intervention, the tail of the pancreas or the tail and a portion of the body of the pancreas are removed. In some cases, the spleen is also removed. This operation is used more often to treat pancreatic NETs found in the tail and body of the pancreas. The determination of resectability is often based on the extent of involvement of the celiac axis [42].

A summary of the outcomes for LDPs are shown in **Table 2**. In brief, the average operation time was 215.2 min, 12% conversion rate, 241.7 ml estimated blood loss, 7.6 days length of hospital stay, 32.5% morbidity rate, 0.3% mortality rate, 21.2% pancreatic fistulas, 10.2% harvested lymph nodes, 89.5% R0 resection, and 46.3% spleen-preserving rate. Comparing these results with the outcomes from conventional open surgery [43, 44], there is a decrease in operation time, estimated blood loss, length of hospital stay, and mortality rate; similar morbidity rates; and an increased rate of pancreatic fistulas and spleen preservation.

Satisfactory oncological outcomes have been reported for LDP in patients with PDA and left-side pancreatic neoplasms [58, 61]. Although some studies reported similar outcomes as open distal pancreatectomy [21], most of the studies reported a clear reduction of blood loss [50, 53, 62, 63, 65] and hospital stay [45, 48, 50, 53, 31, 59, 61–65]. An increase in quality of life is reported when compared to the conventional approach [46]. Similar costs for the laparoscopic and open approaches are reported [63]. The increased OR cost associated with LDP is often offset by the shorter hospitalization and lower overall cost of postoperative care [57].

Regarding the spleen-preserving rate, results stated that it is worth to attempt laparoscopic spleen-preserving DP in patients with a presumed benign to borderline tumor of the body-tail of the pancreas [54]. The most positive results were reported for the splenic vessels preservation technique regarding the conservation of the spleen [51, 66].

	N	Conv. (%)	Time (min)	EBL (ml)	LHS (days)	Morb. (%)	Mort. (%)	PF (%)	LN (%)	R0 (%)	SP (%)
[21]	64	32.8	213	275	8	16		11	8	62	79.6
[45]	535	22.8			7		0		15	86	
[46]	100	23	239	464	7.7	66	0	53		73.3	
[47]	94							0	11		
[48]	71	9.1	250	150	5	28.2	0	11		97.2	15.5
[49]	67	14.9	203	100	6	21	1.5	19	6		
[50]	107	30	193	150	5	27	0	15		97	21
[51]* †	55	9	214.7	342.8	8.2	27.3	0	16			93.4
[51]* †	85	13	199.2	288.9	10.5	38.8	0	26	3		84.7
[52]	132	6.1	156.5	197.4	6	43.2	0.8	21	8	96.2	9.8
[53]	131	31.3	193	262	5	32	0	8	11	100	22.1
[54]	100	2	207		8.7	49	0	27		98	41
[55]	143	5.6	236	334				17			
[56]	902	6.4	316	243	18.9	23.6		66	11		32
[57]	70	7.1	145	113	5.8	49	0	36	5		
[58]	196	2.5	220	250	8	31.9	0	24	10	83.8	
[59]	144	39.5			6.8		0		17	87	
[60]	70	7.1	239		9	25.7	0	19	3	75.7	
[61]	359		195		8	12	0	28	20	91.6	49.6
[62]	82	7	188	70	4	32.9	0	13		97	12
[63]	100	4	214	171	6.1	34	3	17	15	100	25
[64]	73	15	352		5	40	0	22		97	
[65]	45	0	158.7	122.6	7.9	26.7		16			53.3
[66]†	70	0	220	352	10.4	32.9	0	17			100
[67]* †	246	0	193.4	378	8.2	32.5	0	20			54.8
[67]* †	203	0	204.4	328	7.7	25	0	4			

N: number of patients; Conv.: conversions; EBL: estimated blood loss; LHS: length of hospital stay; Morb.: morbidity rate; Mort.: mortality rate; PF: pancreatic fistulas; LN: lymph nodes; R0: R0 resection rate; SP: spleen preserving.
*Two groups.
†Spleen-preserving DP.

Table 2. Reported outcomes in laparoscopic distal pancreatectomy.

With growing surgical experience and refinement in the surgical technique, the indications for LDP have substantially broadened [52]. In this sense, the learning curve appeared to have been completed after 17 procedures [68], but strict selection criteria, high-volume hospital, and experienced team in open pancreatic surgery may play an important role in shortening this learning curve [69].

2.2. Laparoendoscopic single-site surgery

Recent interest in improving cosmetic outcomes has led to laparoendoscopic single-site surgery (LESS) being performed in a variety of procedures. In this sense, LESS is now consolidated as a real alternative to conventional laparoscopic surgery, with numerous studies sustaining its feasibility and therapeutic safety. However, single-site pancreatectomy has been explored and described only in recent years, and therefore, literature is limited to DP procedures and mostly to single case reports or small case series, as it is considered to be a challenging procedure. Only one study has been found for a PD through the single-site approach [70]. In this case, a surgical resection for a malignant melanoma metastatic to the pancreas was performed. The resection was carried out preserving the pylorus. No detailed information about the intervention and surgical outcomes were reported.

	N	Conv. (%)	Time (min)	EBL (ml)	LHS (days)	Morb. (%)	Mort. (%)	PF (%)	LN (%)	R0 (%)	SP (%)
[23]	20		176		2	4	20	20	0	100	90
[24]	14	7.1	166.4	157.1	7.6	0	7.1	0			50
[71]	1	0	330	100	7	1		100	0	100	0
[72]	1	0	170		5		0			100	0
[73]†	1	0	233	<100	3		0			100	100
[74]	12	20	279.8	185	12.2	3	41.6	25		100	33.3
[75]	8	0	145	225	6	2	50	25		100	62.5
[76]*	2	0	232.5	100	7, 5		0	100			
[77]	1	0			5	0			0	100	0

N: number of patients; Conv.: conversions; EBL: estimated blood loss; LHS: length of hospital stay; Morb.: morbidity rate; Mort.: mortality rate; PF: pancreatic fistulas; LN: lymph nodes; R0: R0 resection rate; SP: spleen preserving.
*Two groups.
†Spleen-preserving DP.

Table 3. Reported outcomes in single-site distal pancreatectomy.

The average operation time reported for LESS distal pancreatectomy (**Table 3**) was 218 min (range 145–330 min), 3% (range 0–20%) conversion rate, 144 ml (range 100–225 ml) estimated blood loss, 6 days (range 2–12 days) length of hospital stay, 15% (range 0–50%) morbidity, 0% mortality, 100% R0 resection, and 42% (range 0–100) spleen-preserving rate. Comparing the results with the conventional laparoscopic approach, there is a decreased rate of conversions, estimated blood loss, length of hospital stay, and morbidity; a similar mortality rate; increased average of pancreatic fistulas and R0 resections; and lower spleen-preserving rate.

Barbaros et al. [71] reported the first transumbilical laparoscopic single-site DP in a patient with metastatic lesions on the pancreas. The patient developed a pancreatic fistula. Haugvik et al. [75] compared the results of 8 single-incision DPs with 16 conventional LDPs. They reported no significant differences in operative time, intraoperative bleeding, resection status, and hospital stay between the two groups. Four surgical complications were reported for LESS and five for the conventional approach, including two patients for each group who developed a pancreatic fistula. There was no conversion to conventional laparoscopic or open surgery in any procedure. No differences between operative and postoperative results were also obtained by Yao et al. [24], who compared the surgical outcomes of 14 transumbilical laparoscopic single-site DPs with seven conventional multiport interventions. One conversion to open surgery and one case of leakage were reported for the LESS interventions. Machado et al. [23] reported 4 cases of pancreatic fistula in a study of 20 DPs. Some cases reported no surgical complications during the intervention [72, 76]. In a case study without using any commercial surgical port for LESS [77], the patient developed fever and leukocytosis after surgery. Bracale et al. [72] presented the first LESS DP for an adenocarcinoma. They reported no postoperative complications after 4 months follow-up.

Spleen preservation is an important issue in patients undergoing DP. However, only a few studies have reported spleen preservation through LESS. Chang et al. [73] reported a case of ransumbilical LESS spleen-preserving DP for a cystic tumor in the body of the pancreas. No surgical complications were reported. In another study, Han et al. [74] compared the results from 12 LESS DPs to 28 cases using a conventional laparoscopic approach. The mean surgery time and hospital stay in the LESS group were significantly longer. The spleen preservation was possible in 60.7% of the patients who underwent the conventional approach and 33.3% for the LESS. No significant differences in intraoperative blood loss, tumor size, conversion rate, and postoperative complications between the two groups were found.

In general, authors stated that single-site laparoscopic PD is a feasible and safe technique [23, 72, 74], which can be successfully performed in selected cases and qualified centers [71, 73]. However, they also stated that it is a very demanding procedure with a steep learning curve [74].

2.3. Robotic surgery

Robotic platforms, as the da Vinci® Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), try to overcome many of the key shortcomings of traditional laparoscopy that include monocular vision, limited degrees of freedom, and the effects of pivot and fulcrum, which make complex tasks difficult to master. However, there are also some drawbacks regarding the use of these systems such as the lack of tactile feedback and their cost, including maintenance. Since its first reported application in 2003 [78], the application of robotic technology in pancreatic interventions has been increasing. The main benefit of robotic-assisted PD in comparison with LPD may be the ease of intracorporeal reconstruction after a long resection [78].

In the scientific literature, most of the studies regarding the robotic-assisted PD and DP are retrospective reviews and case reports (**Table 4** and **5**). The average operation time reported for robot-assisted PD (**Table 4**) was 489.1 min (range 410–568 min), 10% (range 0–22%) conversion rate, 324 ml (range 250–400 ml) estimated blood loss, 13.4 days (range 9–22 days) hospital stay, 48.6% (range 21–67%) morbidity rate, 3.8% (range 1–7%) mortality rate, 17.4% (range 7–30) pancreatic fistulas, 29% (range 11–70%) harvested lymph nodes, and 91% (range 87–95%) R0 resection. Comparing the results with conventional laparoscopic approach, operative time, length of hospital stay, and negative resections margins are similar; the rate of conversions, morbidity, mortality, and pancreatic fistulas are increased. Positive results have been obtained for robotic-assisted PD in patients with aberrant or anomalous hepatic arterial anatomy [22]. In a prospective analysis with 150 patients, Polanco et al. [79] concluded that larger body mass index, higher EBL, smaller tumor size and smaller duct diameter are the main predictors of postoperative PF in robot-assisted PD. It appears that the learning curve for robot-assisted PD is attained within 80 cases [80].

	N	**Conv. (%)**	**Time (min)**	**EBL (ml)**	**LHS (days)**	**Morb. (%)**	**Mort. (%)**	**PF (%)**	**LN (%)**	**R0 (%)**
[22]*	112	0	500	250	9.5	63.3	6.7	7	20	92.6
[79]	150	7.3	515	300				17		
[80]	200	6.5	483	250	9	67.5	3.3	17	11	92
[84]	60		410	400	20	35	1.7	13	23	94.7
[85]	50	22	421	394	22			30	70	90
[86]	50	16	568	350	10	56	2	20	36	89
[87]	132	8.3	527	>400	10	21	5.3	17	14	87.7

N: number of patients; Conv.: conversions; EBL: estimated blood loss; LHS: length of hospital stay; Morb.: morbidity rate; Mort.: mortality rate; PF: pancreatic fistulas; LN: lymph nodes; R0: R0 resection rate; SP: spleen preserving.
*Two groups.

Table 4. Reported outcomes in robotic-assisted pancreaticoduodenectomy.

	N	**Conv. (%)**	**Time (min)**	**EBL (ml)**	**LHS (days)**	**Morb. (%)**	**Mort. (%)**	**PF (%)**	**LN (%)**	**R0 (%)**	**SP (%)**
[45]	535	23			7				3	86	
[82]	100	2	246	150		72	0	42	13	95.7	
[83]	55	0	278.2		12.6	61.8	0	53	58	100	61.8
[87]	83	2.4	256	>200	6	13	0	43	17	97	
[88]†	69	0	150	100	11.6	40.6	0	25	22	100	65.2

N: number of patients; Conv.: conversions; EBL: estimated blood loss; LHS: length of hospital stay; Morb.: morbidity rate; Mort.: mortality rate; PF: pancreatic fistulas; LN: lymph nodes; R0: R0 resection rate; SP: spleen preserving.
†Spleen-preserving DP.

Table 5. Reported outcomes in robotic-assisted distal pancreatectomy.

Regarding robot-assisted DP, the average operation time was 232.6 min (range 150–278 min), 5.5% (range 0–23%) conversion rate, 125 ml (range 100–150 ml) estimated blood loss, 9.3 days (range 6–13 days) hospital stay, 46.9% (range 13–72%) morbidity rate, 0% mortality rate, 40.7% (range 24–53%) pancreatic fistula, 22.6% (range 3–58%) harvested lymph nodes, 95.7% (range 86–100%) R0 resection, and 63.5% (range 62–65%) spleen-preserving rate. Comparing these results with the conventional laparoscopic approach, there is a decreased conversion rate and EBL; and increased operation time, length of hospital stay, morbidity, rate of pancreatic fistulas, R0 resections, and spleen-preserving rate. Morbid obesity and technical difficulty seem to be the two most common reasons for conversion from robotic-assisted hepatobiliary and pancreatic surgery [81]. It appears that the learning curve for robot-assisted DP is approximately 10–40 cases [82, 83].

3. Image-guided techniques for pancreatic surgery

In order to cope with some of the limitations in MIS and guide the surgeon during the surgical procedure, image-guided techniques have been developed. The lack of tactile feedback and 3D sensation in video-assisted surgery accelerated the need for these techniques. In addition, for the human eye, several pathologies, such as the presence of nonsuperficial tumors, are not easily distinguishable from surrounding normal tissue. This makes, in some occasions, decision-making during surgery a very difficult process. During image-guided surgery, diagnostic imaging is used in conjunction with images from the operative field to improve the localization and targeting of pathologies, as well as to monitor and control treatments. The combination of tracking technologies for recording the position of the patient and the surgical instruments with preoperative and intraoperative images provides a comprehensive assistance tool for guiding any MIS intervention [27, 89–91]. Image-guided technology allows for more precise and accurate procedures, allowing surgeons to decide the best approach to address a specific disease before the intervention [92].

Radical surgical resection of tumor tissue is currently the best chance for cure. However, this option is only suitable for a minority of patients, and surgical procedures are complex with high rates of local recurrence. The presence of microscopic residual tumor tissue at the resection margins is one of the main prognostic factors, and therefore optimizing the surgical procedure to prevent positive resection margins is of the utmost importance. Accordingly, intraoperative margin assessment and visualization techniques, as well as image-guided techniques may be advantageous in guiding the surgeon to achieve curative resections.

3.1. Laparoscopic ultrasound (LUS)

Advances in technology over the last 30 years have seen the application of laparoscopic ultrasound (LUS) expand beyond its initial limited diagnostic role to assisting in tumor staging, guiding intervention, locating lesions intraoperatively, assessing anatomic relationships, and in directed therapy [93–95]. The main application of LUS during pancreatic and liver surgery is providing real-time imaging guidance for resectability assessment and detection of vessel involvement, aiming to decrease the number of irradical resections [95]. The reported overall sensitivity, specificity, and accuracy of combined diagnostic laparoscopy and LUS in predicting resectability has been reported to be 100, 91, and 96%, respectively [96]. LUS should be considered for confirmation of staging of disease when there is a strong suspicion of unresectability and tumor borders are not clearly defined by CT scan [96].

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LUS plays an integral part in the management of cystic lesions of the pancreas, particularly the characterization of suspected intraductal papillary mucinous neoplasms (IPMNs) [95, 97, 98]. IPMNs appear as well-defined hypoechoic masses with associated posterior enhancement. The malignant potential of IPMNs is directly related to its relationship with the main pancreatic duct and adjacent blood vessels (**Figure 1**). LUS allows defining the cysts borders (**Figure 2**) and evaluating the relationship of the lesion with the main duct and any major vessels [95, 98, 99].

Figure 2. LUS image of a pancreatic cystic tumor. The lesion appears as a hypoechoic mass (yellow arrow).

In the case of pancreatic adenocarcinomas, they appear as a homogeneous hypoechoic mass with poorly defined margins. Large tumors can display a mixed echogenicity. A sensitivity of 90% for assessing positive lymph nodes and 100% for venous invasion have been reported for laparoscopy combined with LUS examination [100]. Regarding NETs, LUS facilitates intraoperative decision-making and demonstrates anatomic details, such as the tumor location and its relation to the adjacent vascular structures and main pancreatic duct [95, 97]. In ultrasound images, NETs typically appear as well-defined, homogeneous, and hypoechoic masses [93]. Findings from LUS inspection help to decide whether to perform either tumor enucleation or resection during laparoscopic intervention [93].

3.2. Fluorescence

Near-infrared (NIR) light (700–900 nm) is a novel imaging technique that can penetrate through several millimeters even centimeters of tissue, revealing targets below the tissue surface [101]. This imaging modality does not use ionizing radiation or direct tissue contact, making it a remarkably safe technique. NIR fluorescent contrast agents can be visualized with acquisition times in the millisecond range, enabling real-time guidance during surgery. Furthermore, as NIR light is invisible to the human eye, it does not alter the look of the surgical field, thus minimizing the learning curve [102]. The main aim of this imaging modality is to fill the gap between preoperative imaging and intraoperative reality.

Fluorescence-guided systems provide an additional tool for diagnosis of pancreatic cancer, real-time image guidance during tumor resection, and inspection to confirm complete resection [103]. This intraoperative modality can assist surgeons to visualize tumors, sentinel lymph nodes, and vital structures in real time [102]. This technology could represent the next step to improving treatment of pancreatic cancer in laparoscopic resections. However, most of the published studies for pancreatic surgery are limited to animal models.

Two main components are needed for fluorescence-guided surgery, fluorescent contrast agents and a NIR camera system. Several intraoperative NIR fluorescence camera systems have been developed for both open and laparoscopic surgery, some of which are commercially available and Food and Drug Administration (FDA) approved [104]. Fluorescent contrast agents contain a fluorescent component (fluorophore), which emits NIR fluorescent light after being excited with a NIR light source. Visualization of the tissue is based on the signal of the contrast agent in the region of interest relative to the background signal, known as signal-to-background ratio.

Indocyanine green (ICG) and methylene blue (MB) are the only NIR fluorophores that are registered with the FDA and the European Medicines Agency for clinical use. ICG emits fluorescent light at ≈800 nm and it is cleared rapidly by the liver and almost exclusively excreted into the bile, permitting imaging of bile ducts. MB has been applied clinically for many years as a visible contrast agent, and when diluted to levels that are almost undetectable to the human eye, MB becomes a fluorophore emitting at ≈700 nm. MB is cleared equally by both liver and kidney, permitting imaging of both bile ducts and ureters. ICG has been shown to accumulate around hepatic metastasis of pancreatic and colorectal cancers [105]. Methylene blue tends to accumulate in NETs after high-dose intra-arterial injection [103, 106]. The chemical structures of both ICG and MB do not allow these agents to be conjugated to tissue-specific, therefore, they are nonspecific NIR contrast agents [102, 107].

Applications of this technique during hepatopancreatobiliary surgery include tumor imaging in liver and pancreas, and real-time imaging of the biliary tree. Pessaux et al. [26] presented a robotic pancreaticoduodenectomy assisted by fluorescence imaging, providing enhanced visualization of the common bile and cystic ducts during the intervention (**Figure 1**). Subar et al. [108] reported a case of a LPD to treat an ampullary lesion in the duodenum. Before the pancreaticojejunostomy, the viability of the margin of the remnant pancreas was assessed with NIR imaging. The NIR technique improved the detection of ischemic tissue of the pancreatic margin after resection. This may lead to an increase in blood supply to the pancreatic anastomosis, and therefore potentially help to decrease the incidence of pancreatic fistulas.

In a study with different pancreatic tumors on three experimental porcine models, we analyzed the usefulness of NIR imaging during laparoscopic pancreaticoduodenectomy and single-site distal pancreatectomy procedures. In two animals, a tumor model was created in the head of the pancreas. In the third animal, the tumor model was developed in the tail of the pancreas. NIR imaging was used as guidance during LPD and LESS distal pancreatectomy. The patency of the hepaticojejunostomy was assessed by means of ICG excretion and fluoroscopic imaging. During surgery, identification of the biliary anatomy and vascular anatomy of the pancreas was possible in all procedures using NIR imaging (**Figure 3**). Biliary excretion of ICG was not clearly visualized during the patency test, but fluoroscopic imaging was positive in one case.

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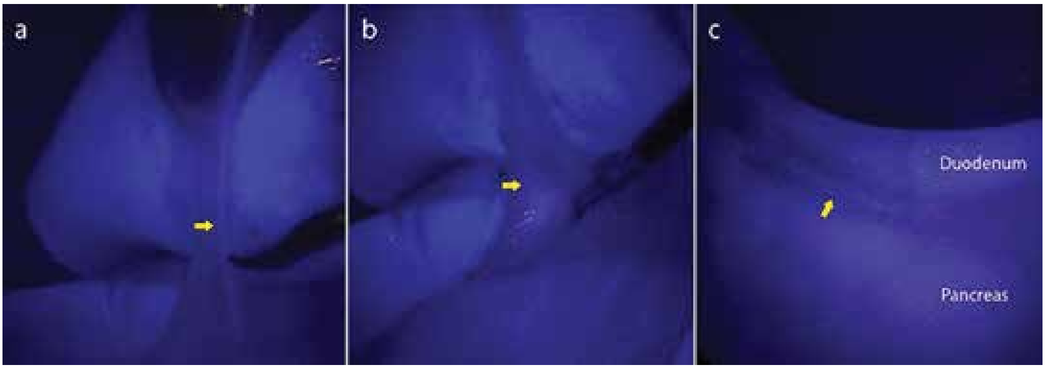

Figure 3. NIR image of biliary and pancreatic anatomy: Cystic artery (a, yellow arrow), cystic duct (b, yellow arrow), and pancreaticoduodenal artery (c, yellow arrow).

To obtain the full advantage of NIR fluorescence imaging for pancreatic cancer visualization, such as tumor imaging, tumor specific NIR conjugated agents need to be designed and tested. The tumor-targeting capability of the fluorophore-conjugated anticarcinoembryonic antigen antibody has been demonstrated in orthotopic models for intraoperative tumor visualization of both primary and metastatic deposits of pancreatic cancer [25, 109]. Metildi et al. [109] concluded that mice treated with fluorescence-guided laparoscopic surgery permitted adequate labeling and distinction of tumor margins before tumor resection, decreasing local recurrence, and increasing survival compared to mice treated with standard bright-light laparoscopic surgery.

3.3. Surgical navigation

Surgical navigation systems (SNS) combine preoperative and intraoperative image information with position and orientation tracking of surgical instruments during the surgical intervention as a surgical decision-making tool helping to improve the safety, accuracy, and efficiency of surgeries [27, 91, 92]. In MIS, due to surgeon having less visual and tactile perception compared to open surgery, image assistance becomes extensively helpful for 3D understanding of the surgical scenario and localization of lesion and essential anatomic structures.

The basic setup of a SNS consists of a preoperative image data (typically MR and CT), a tracking system (mainly electromagnetic or optical), a computer platform with screen, and the respective navigation software [89]. The combination of image-guided surgery with navigation technology consists of several steps, which are critical to ensure safety and accuracy of a procedure [27]: (1) acquisition of preoperative images and visualization for optimal diagnosis and planning, (2) accurate registration of preoperative data to the patient coordinate space and visualization in the OR, (3) intraoperative image acquisition and visualization/fusion with the preoperative images to update for anatomical shifts, and (4) postoperative imaging and visualization for evaluation of the surgical treatment.

Despite the use of navigation systems, abdominal surgery is still a challenging task. Commercial SNS are available for resection and ablation procedures of the liver (example: CAScination AG, Switzerland). However, to the best of our knowledge, no commercial systems are available or studies in the scientific literature have been published regarding the use of SNS for assistance during pancreatic cancer surgery.

We were recently able to demonstrate the usefulness of the CustusX navigation system for image guidance during a patient case, a distal pancreatectomy for the resection of a cystic tumor in the body of the pancreas (unpublished case). CustusX is an open-source navigation research platform for image-guided interventions [91]. This platform has been successfully used for many clinical applications such as neurosurgery, spine procedures, bronchoscopy, endovascular therapy, and laparoscopic procedures like adrenalectomy and lately for liver and pancreas surgery [91, 110–112].

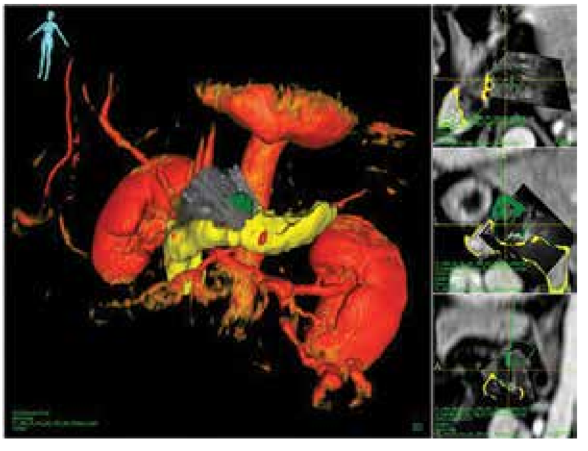

Figure 4. Snapshot of the CustusX platform during a distal pancreatectomy. The tumor is shown in green and the pancreas in yellow. The US imaging is superimposed on the 3D model from a preoperative MRI scan.

Prior to surgery, MR and CT images were acquired and imported into the navigation system software for reconstruction into 3D. The anatomical structures of interest, including the pancreas, tumor, and vessels were segmented semiautomatically [112]. The navigation system was integrated with a LUS probe running on an ultrasound scanner (Ultrasonix, Canada) with digital research interface to the navigation system. The probe was tracked by an electromagnetic sensor integrated in the tip. A probe calibration was carried out in a laboratory using a robotic arm and a well-defined geometric structure in a water tank [113]. An intraoperative registration procedure was carried out to combine the intraoperative LUS with the corresponding preoperative MR and CT images, displaying them simultaneously (**Figure 4**). This enabled the location of the lesion based on multimodal display, providing a useful tool for the surgeons to identify the anatomical structures of interest, meet their relation to other adjacent structures, and define safely and accurately the resection margin during the course of the distal pancreatectomy.

3.4. Augmented reality

Another available technology for intraoperative surgical guidance is augmented reality (AR). In surgery, AR is the fusion of artificial computer-generated images (3D virtual model) generally obtained from preoperative medical imaging and real-time patient images with the aim to visualize unapparent anatomical details. This results in the visualization of internal structures through overlying tissues, providing a virtual transparent vision of surgical anatomy. Potential advantages of the use of this imaging technology in surgery include the delineation of dissection planes or resection margins and the avoidance of injury to invisible structures.

The registration process is one of the main challenges of AR, in which the virtual model and intraoperative images should be merged in real time. In this sense, intraoperative accuracy is highly affected by mobile or deformable structures due to the heartbeat, ventilation, or laparoscopic insufflation.

A method to overlay anatomical information from preoperative CT studies onto the patient's body surface during gastrointestinal, hepatobiliary, and pancreatic surgery was presented by Sugimoto et al. [114]. For enabling the simultaneous display of the gastrointestinal tract and pancreatobiliary duct with associated blood vessels, a carbon dioxide-enhanced virtual multiple detector CT cholangiopancreatography was performed. Manual registration based on physiological markers was used. However, this method does not deal with possible alteration of the patient anatomy during the course of the surgery. A robotic pancreaticoduodenectomy assisted by AR was presented by Pessaux et al. [26]. In this study, a 3D virtual model of the patient from a preoperative CT scan was manually merged with the stereoscopic images from the da Vinci® robotic system.

4. Conclusions

Pancreatic cancer has a high mortality rate and, at the time of diagnosis, the number of patients with potentially resectable tumors is considerably low. Surgery is still the only viable option for treatment of pancreatic cancer. However, surgical procedures for pancreatic resection are complex and require high surgical expertise. Pancreatic tumors can be treated through laparoscopic surgery with similar outcomes to the conventional approach. In general, studies reported that minimally invasive pancreatic surgery is feasible, safe, and with a steep learning curve. Laparoscopic procedures reported a reduction of blood loss, length of hospital stay, and positive resection margins, as well as an improvement in spleen-preserving rates when compared to open surgery. Laparoendoscopic single-site surgery reduces the blood loss and morbidity, compared with the conventional laparoscopic approach. In robot-assisted pancreatic surgery, reported surgical outcomes are similar to laparoscopic surgery, with an apparent increase in the splenic preservation rate and negative resection margins.

Laparoscopic pancreatic surgery has some technical limitations for the surgeon such as the reduced tactile and visual information. Besides, intraoperative tumor identification may be a challenging task in some cases due to the anatomical location of the pancreas, nearby major vascular structures, and frequently inflamed surrounding pancreatic tissue. These limitations may significantly impact the surgical procedure to prevent positive resection margins. Image-guided techniques provide intraoperative margin assessment and visualization methods, which may be advantageous in guiding the surgeon to achieve curative resections, resulting in improved surgical outcomes. Reported cases of fluorescence-guided pancreatic surgery showed that this imaging technique could be beneficial in surgeries where the pancreatic anatomy is difficult to identify. Navigation systems combine preoperative and intraoperative imaging, providing location of the anatomical structures of interest with respect to surgical instruments as well as the extent of the tumor to be addressed, which allows for a safe and precise definition of resection margins. Thus, surgeons will have a comprehensive system to support and guide pancreatic surgeries, with the ultimate goal of improving surgical outcomes and increase the rate of negative resections and the subsequent positive effect on the life expectancy of the patient.

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Chapter 4

Laparoscopic Left Adrenalectomy with Submesocolic and Retropancreatic Approach

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Additional information is available at the end of the chapter

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Abstract

Introduction: The safety and efficacy of laparoscopic transperitoneal lateral adrenalectomy and retroperitoneoscopic adrenalectomy have been reported. The aim is to report the authors' experience in laparoscopic left adrenalectomy with an alternative transperitoneal submesocolic and retropancreatic approach with patient supine.

Research methods: The authors have performed laparoscopic transperitoneal submesocolic, retropancreatic adrenalectomy for both benign and malignant, functioning lesions >4 cm in diameter or with smaller lesions but having an imaging pattern suspicious of malignancy or of sub-clinically secreting tumors. After opening the posterior peritoneum at the root of the transverse mesocolon and Gerota's fascia, the junction of the inferior adrenal vein with the left renal vein is identified. The adrenal vein is then prepared and divided, followed by mobilization and removal of the left adrenal gland.

Conclusion: Early ligation of the adrenal vein is the most relevant technical feature of this procedure to avoid the release of catecholamines, hormones or neoplastic cells which could occur during manipulation of the gland prior to ligation of the main adrenal vein. Moreover, this approach makes it possible to perform associated procedures, including a bilateral adrenalectomy, without the need to reposition the patient on the operative table, but simply by positioning additional trocars.

Keywords: adrenal tumors, laparoscopic adrenalectomy, pheochromocytoma, transperitoneal anterior approach, submesocolic retropancreatic approach

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1. Introduction

The surgical approach to the adrenal gland has raised debate among surgeons due to its retroperitoneal location and for the complexity in the management of secreting tumors, particularly in case of pheochromocytoma (PHE) [1–3]. Traditionally, open adrenalectomy is made difficult due to its deep anatomical location, and it is associated with up to 39% morbidity rate and prolonged hospital stay [1–3]. In 1992, Gagner described the first laparoscopic adrenalectomy (LA) by a transperitoneal approach with the patient in the lateral decubitus position [4, 5]. This initial experience has been followed by others using the same approach or, alternatively, the retroperitoneal approach with the patient in the prone or in the lateral decubitus position [6, 7] and the transperitoneal approach with the patient supine [8]. Several reports have confirmed the safety and efficacy of these techniques, and minimally, invasive adrenalectomy is presently considered the treatment of choice for a variety of benign lesions, including lesions of the medulla [9, 10].

The aim of the present chapter is to report the authors' experience with left laparoscopic adrenalectomy (LA) using an original transperitoneal submesocolic and retropancreatic approach with patient supine, to describe the patient's preparation for surgery as well as the operative details of this procedure.

2. Methods

In order to establish the diagnosis in case of adrenal secreting lesions, all patients undergo complete hormonal evaluation as previously reported [11]. Diurnal serum cortisol, dehydroepiandrosterone (DHEAS), plasma adrenocorticotropic hormone (ACTH), testosterone, androstenedione, urinary free cortisol (UFC), 17-hydroxyprogesterone (17-OHP), renin activity, aldosterone and urinary catecholamine levels are measured, together with overnight 1-mg dexamethasone suppression test (DST) [11]. Aldosterone-producing adenoma, pheochromocytoma and Cushing's syndrome are diagnosed on the basis of high plasma aldosterone, plasma renin activity (PRA) ratio (>40) and unsuppressed aldosterone after sodium load, elevated urinary metanephrines, elevated UFC, abnormal serum cortisol, inadequate cortisol suppression after 1-mg dexamethasone and low and/or suppressed plasma ACTH [11]. When no specific signs and/or symptoms of autonomous hormone secretion are present, or abnormal hypothalamus-pituitary-adrenal axis tests and radiological imaging suggesting the presence of an adrenocortical lesion, a diagnosis of nonfunctioning adenoma is made [11].

All patients are studied with computed tomography (CT) scan and magnetic resonance imaging (MRI). An attenuation value of 1O or less Hounsfield units (HU) on unenhanced CT scan is suggestive for the presence of a benign adrenocortical adenoma [12]. Relative contrast washout of >40% and an absolute contrast washout of >60% are suggestive for an adenoma, with 92% specificity and 98% sensitivity rates, respectively [13, 14]. In all sequences during MRI, adrenocortical adenomas are homogeneous, with mild gadolinium enhancement [12], with low or equal signal intensity as the liver on T2-weighted images may appear on lower signal intensity than the rest of the adrenal gland [12]. Chemical shift imaging can be done during MRI to identify fat within the lesion as decreased signal intensity relative to normal tissue [12]. For carcinomas, the attenuation on unenhanced studies is higher than 10 HU on CT scan [15]. On contrast-enhanced studies, carcinomas enhance greedily due to their vascularity, and the enhancement pattern may be homogeneous, unless there is central necrosis [15, 16]. The relative percentage washout of carcinomas is <40% [17]. At MRI, adrenal carcinomas are noted for heterogeneity on T1-weighted images, with intermediate to high signal intensity [18]. Heterogeneity is also noted on T2-weighted images due to hemorrhage and/or necrosis [18]. Based on these criteria, adrenal lesions larger than 4 cm in diameter or with smaller but having an imaging pattern suspicious of malignancy or of sub-clinically secreting tumors are an indication for laparoscopic adrenalectomy.

2.1. Patient's preoperative preparation

2.1.1. Pheochromocytoma

Alpha-blockers (doxazosin 20 mg/day), starting at least 15 days before surgery, are administered. If patients reported episodes of tachycardia, beta-blockers are also administered (atenolol 100–200 mg/day orally). On the day before surgery, treatment with alpha-blockers is discontinued, and intravenous (iv) normal saline 2000 cc is administered to expand the plasma volume [19].

2.1.2. Conn's syndrome

Iv hydrocortisone 100 mg is administered at induction of anesthesia. Iv spironolactone is used for potassium control [20].

2.1.3. Cushing's syndrome

Iv hydrocortisone 100 mg is administered at induction of anesthesia and then iv hydrocortisone 50 mg every 8 h [20].

2.2. Surgical technique

2.2.1. Left adrenalectomy: transperitoneal anterior submesocolic and retropancreatic approach

Surgery is performed under general anesthesia. An orogastric tube and urinary catheter are positioned. Intraoperative patients' monitoring includes intra-arterial radial artery catheter for continuous blood pressure measurement and a central venous catheter (subclavian or internal jugular access) for rapid infusion of liquids. Pneumoperitoneum is usually established with a Veress needle at the umbilicus or with an open technique and Hasson cannula, in case of the presence of abdominal scars from previous surgery. Pneumoperitoneum is set at a pressure of 12–13 mmHg, with carbon dioxide flow adjusted at 30 lt/min. Four trocars and a 30°/45°

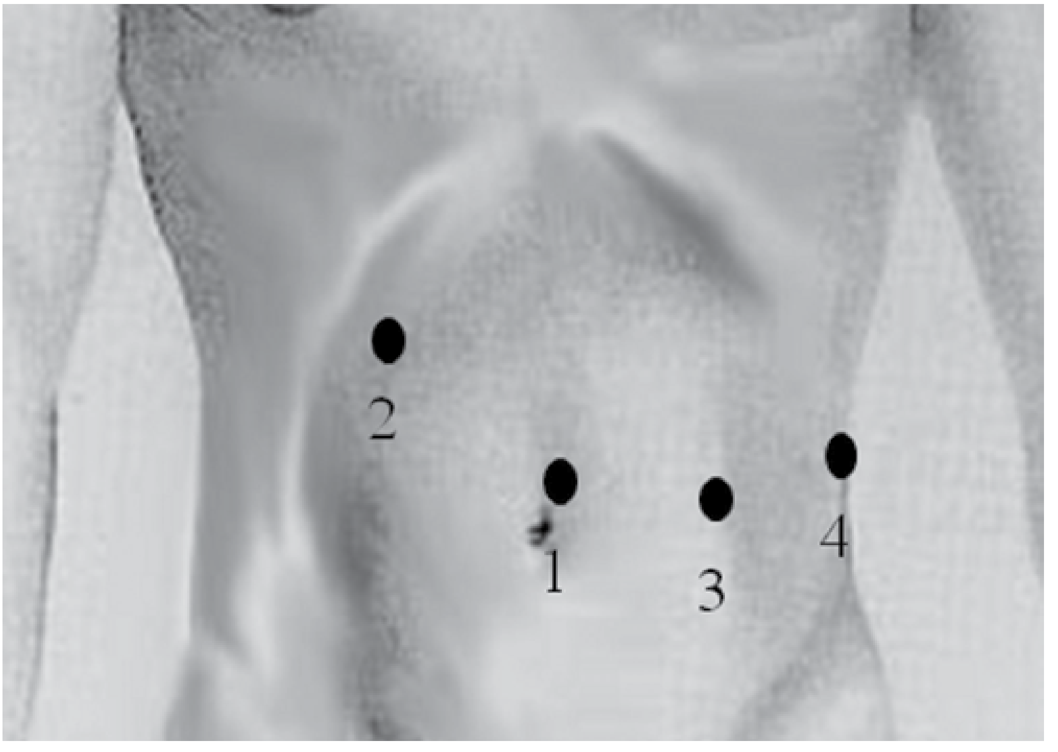

Figure 1. Trocars' position during left transperitoneal submesocolic and retropancreatic adrenalectomy. The surgeon and first assistant stand on the left of the patient, while the second assistant stands on the right.

forward oblique optic are used. This approach is performed with the patient supine, in slight anti-Trendelenburg position and with the operating table turned 30° with the side opposite the lesion down, to facilitate exposure of the surgical field. The surgeon stands on the side which is ipsilateral to the lesion.

After induction of pneumoperitoneum, the first 12-mm optical trocar (n. 1) is inserted on the left of the midline above the umbilicus (**Figure 1**). A second 12-mm trocar (n. 2) is inserted under vision on the right midclavicular line below the right costal arch. The third and fourth 12-mm trocars are placed one on the left midclavicular line along with the transverse umbilical line (n. 3) and other on the left anterior axillary line (n. 4), respectively (**Figure 1**). The 10-mm laparoscope is introduced from trocar (n. 3), while trocars 1 and 4 are the operating ones. With atraumatic forceps introduced from trocar (n. 2), the transverse mesocolon is raised by the assistant. This maneuver discloses the first jejunal loop at the ligament of Treitz, and it shows the arch of the inferior mesenteric vein. The operative table is tilted with the left side of the patient up, which allows the surgeon to displace the first jejunal loops on the patient's right side (**Figure 2**). The posterior peritoneum is opened at the insertion of the transverse mesocolon and posteriorly to the lower edge of the pancreas, between the first jejunal loop and the arch of the inferior mesenteric vein or immediately lateral to this vessel, according to

Figure 2. After raising the transverse mesocolon and displacing the first jejunal loop on the patient's right side, the posterior peritoneum is divided close to the arch of the inferior mesenteric vein.

its distance from the jejunum. Toldt's fascia appears at this point as a whitish film. The dissection then proceeds posteriorly along the retro-pancreatic space, after raising the body of the pancreas with an atraumatic instrument held by the surgeon's left hand. The splenic vein is visible at this point running along the posterior aspect of the pancreas. Gerota's fascia is now opened to visualize the left renal vein, which is followed medially, until the left inferior adrenal vein is identified. This is cautiously prepared and divided between clips (AcuClip, Tyco/Healtcare, Norwalk, Connecticut, USA, **Figure 3**). No manipulation of the left adrenal gland has yet occurred prior to division of the adrenal vein because the gland is located cranially to this vessel. Only at this point, the gland is mobilized using a radiofrequency (LigaSure™ tissue fusion, Covidien, Mansfield, Massachusetts, USA) or ultrasonic (Ultracision, Harmonic Scalpel, Ethicon Endo Surgery, Cincinnati, Ohio, USA) device, and the specimen is removed from the abdominal cavity inside a specimen retrieval bag after slightly enlarging the periumbilical trocar incision [19].

Near-infrared indocyanine green (NIR-ICG) fluorescence may be employed during surgery and may be useful to aid in vascular structures and adrenal gland identification amidst retroperitoneal and perirenal fat, particularly in obese patients, to improve the safety of laparoscopic adrenalectomy.

Figure 3. The left adrenal vein is divided between clips. Confluence of the diaphragmatic vein to the left adrenal vein is visible.

3. Discussion

Surgery is the standard treatment of Conn's syndrome, Cushing's disease, pheochromocytoma, primary adrenal cancer and adrenal metastases. After the introduction of minimally invasive adrenalectomy, this has now become the treatment of choice [8, 21–26]. Minimally, invasive adrenalectomy is mostly performed either with a transperitoneal lateral approach or with a retroperitoneal approach [4]. The laparoscopic transperitoneal anterior approach has been proposed only by few centers [8, 11, 19, 23, 24, 26].

The transperitoneal lateral approach, originally described by Gagner et al. [4], is performed with the patient in the lateral decubitus position. It gives excellent exposure of the operative field with a wide working space, and it facilitates orientation by providing readily identifiable anatomical landmarks [27]. Its proponents report several advantages, such as a rapid and direct access to the gland without the need to retract any organ and with minimal patient trauma [28], a clear operative field due to gravity that keeps blood and bowel away from it and the need for less surgical dissection on the left side, as compared to the anterior approach [26]. By the authors' opinion, the main disadvantage of the lateral approach is that it does not provide early ligation of the adrenal vein prior to gland manipulation, which the authors

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believe to be important so as to avoid pressure instability in case of secreting adenomas, and particularly of pheochromocytoma, and which would also be oncologically correct [11, 19, 29].

Retroperitoneal adrenalectomy (RA) has also been reported to be safe and effective [21, 30, 31]. According to its proponents, it is preferred to reduce the risks and possible complications of a transperitoneal access, such as incisional hernias and paralytic ileus from bowel manipulation [4, 7]. It has been reported to require less analgesics due to lower postoperative pain [27] and to be associated with earlier recovery of bowel function, possibly leading to shorter hospital stay [27]. However, minimal postoperative pain, early liquid diet and a short hospital stay have been reported also after a laparoscopic approach [5, 6, 26, 27]. RA is preferred in patients with abdominal adhesions from previous surgery and in obese patients [32]. Moreover, several authors reported a shorter operative time [28]. According to Walz et al. [33], a 7 cm hormonally active tumor or a 4–7 cm nonfunctioning tumor may be indications for a retroperitoneal approach. By the opinion of these authors, severe obesity, simultaneous abdominal pathology, patients with evident signs of malignancy or a tumor exceeding 8 cm are contraindications for the retroperitoneal approach [33]. In our opinion, the patient's position during RA is unfavorable for rapid conversion to open surgery in case of major bleeding and may itself impair or worsen the hemodynamic conditions of the patient [8].

Moreover, both lateral LA and RA do not allow to perform associated surgical procedures [11, 19, 34]. In lateral LA, exploration of the contralateral gland is not possible without repositioning the patient [11, 19, 34], which increases the operative time.

To reduce the risk of catecholamines, hormones or neoplastic cells spread from the adrenal gland, the authors introduced the laparoscopic transperitoneal submesocolic and retropancreatic approach with the patient supine. This approach was originally described by Pierre Delbet in 1912 [35]. Its main advantages are the limited extent of the dissection and early identification, ligation and division of the left adrenal vein which is obtained prior to any gland manipulation. This aspect is particularly important in case of secreting lesions. In fact, the authors consider early clipping of the main adrenal vein to be of upmost importance, together with avoiding any manipulation of the gland prior to adrenal vein ligation [11, 19, 24, 26, 36].

With respect to the transperitoneal anterior and lateral approaches, it does not require mobilization of the left colonic flexure or of the spleno-pancreatic complex to gain access to the adrenal gland, with reduction of the operative time and of potential operative risks. However, it does require experience in advanced laparoscopic surgery because the operation is conducted in a restricted working space adjacent to major venous vessels, such as the left renal and splenic veins, and the aorta [11, 19, 37].

In case of LA or RA for pheochromocytoma, because of the complexity of the disease, the operation should be performed only in centers with a well established, multidisciplinary experience in the diagnosis and treatment of adrenal gland pathology. In fact, surgery for pheochromocytoma is at risk of hypotensive or hypertensive crisis, or both, due to an excess in catecholamine release, which cannot be completely prevented even by adequate preoperative preparation with α-blockers [10]. The aim of medical treatment prior to surgery is not the reduction of hormonal secretion but the prevention of the peripheral effects of catecholamines secreted by the tumor, so that the patient may undergo surgery under the best cardiovascular conditions [38]. Advances in intraoperative monitoring and the introduction of preoperative α1-receptors' blockade have radically reduced the mortality rate [39]. A significant increase in the rates of plasma norepinephrine release related to mobilization of the adrenal gland has been reported during LA with a lateral approach [39]. One study also reported that severe hypertension was triggered by direct manipulation of the adrenal gland [10]. Instead, no significant intraoperative change in blood pressure was observed following this surgical strategy in case of pheochromocytoma [19]. Based on the authors' data, the anterior laparoscopic submesocolic and retropancreatic approach for treatment of secreting adrenal lesions is safe [11, 19, 24].

Authors	*N*	Approach	Mean age (years)	Mean oper. time (min.)	Conversion (%)	Morbidity (%)	H.S. (days)
Hazzan [2]	24	Lateral	45.4	188	7	16	4
Vargas [3]	20	Lateral	47	193	10	10	3.1
Gagner [5]	100	Lateral	46	130	3	12	2.5
Bonjer [6]	79	RP	50	114	6.3	10.1	2
Salomon [7]	21	RP	46	116	0	19	3.4
Lang [9]	56	RP	36.2	52	1.8	1.7	5.2
Janetschek [10]	19	Lateral	49.7	150	0	16	7
Mohammadi-Fallah [27]	11	Lateral	43	129	0	9.1	3.6
	12	RP	42	128	8.3	8.3	3.1
Dickson [30]	23	Lateral	42	145	4.3	8.7	3.1
	23	RP	47	100	13	13	1.9
Fernández-Cruz [31]	16	Lateral	36	89	12.5	12.5	3
	14	RP	47	105	14.2	0	2.75
Walz [33]	560	RP	49.2	67	1.7	11.8	–
Cabalag [44]	13	Lateral	47	105	0	30.7	2
	10	RP	61	90	0	10	1
Paganini [11]	19	LASA	54	92	0	0	4.4
Paganini [19]	37	LASA	54	82.7	0	0	3.85
Matsuda [29]	75	Anterior	–	221	0	3.9	10.2
Linos [45]	18	Anterior	48.7	116	5.5	0	2.3

N, number of patients; H.S, hospital stay; RP, retroperitoneal; LASA, left anterior submesocolic approach.

Table 1. Patient series reported in the literature.

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Some authors [40, 41] consider tumors larger than 6 cm to be a contraindication for a minimally invasive approach, due to the risk of malignancy. In the authors' experience, the size of the largest lesion up to 10 cm in diameter did not affect the feasibility and the outcome of the procedure or the operative time [11, 19, 24]. This observation has been confirmed by Parnaby et al. [42], whose results are in agreement with the authors' experience [11, 19, 24].

Moreover, the supine position of the patient allows one to perform associated diagnostic [43] or operative procedures, such as contralateral adrenalectomy, without the need to reposition the patient on the operative table. In the authors' experience, the submesocolic approach was associated with a significant reduction in the operative time, as compared to the laparoscopic traditional anterior approach, which compares favorably also with the operative time of the lateral and retroperitoneal approaches reported in the literature (**Table 1**) [2, 3, 5–7, 9–11, 19, 27, 29–31, 33, 44, 45].

Independently from the approach that is followed, the recent introduction of a dedicated laparoscopic instrumentation to detect near-infrared fluorescence with indocyanine green (NIR-ICG) improves visualization of the inferior adrenal vein and of the adrenal gland with respect to the surrounding fat, making their identification easier [46, 47]. In the authors' opinion, this instrumentation might improve the safety of the procedure, as well as the oncological outcome in case of adrenal cancer or metastases.

LA with transperitoneal submesocolic and retropancreatic approach has proven to be safe and effective [11, 19, 24], and its results are in line with those reported in the most recent literature [48] after RA and lateral LA. Early ligation of the adrenal vein is the most important technical feature of this technique in every type of lesion. For more objective results, a multicenter randomized clinical trial comparing the submesocolic approach with lateral LA and RA for left adrenalectomy would be required.

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Chapter 5

Ergonomics in Laparoscopic Surgery

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Additional information is available at the end of the chapter

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Abstract

Despite the many advantages for patients, laparoscopic surgery entails certain ergonomic inconveniences for surgeons, which may result in decreasing the surgeons' performance and musculoskeletal disorders. In this chapter, the current status of ergonomics in laparoscopy, laparoendoscopic single-site surgery (LESS), and robot-assisted surgery will be reviewed. Ergonomic guidelines for laparoscopic surgical practice and methods for ergonomic assessment in surgery will be described. Results will be based on the scientific literature and our experience. Results showed that the surgeon's posture during laparoscopic surgery is mainly affected by the static body postures, the height of the operating table, the design of the surgical instruments, the position of the main screen, and the use of foot pedals. Ergonomics during the laparoscopic surgical practice is related to the level of experience. Better ergonomic conditions entail an improvement in task performance. Laparoscopic instruments with axial handle lead to a more ergonomic posture for the wrist compared to a ring handle. LESS is physically more demanding than conventional and hybrid approaches, requiring greater level of muscular activity in the back and arm muscles, but better wrist position compared with traditional laparoscopy. Physical and cognitive ergonomics with robotic assistance were significantly less challenging when compared to conventional laparoscopic surgery.

Keywords: Ergonomics, laparoscopic surgery, laparoendoscopic single-site surgery, robotic instrument, electromyography, motion capture

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1. Introduction

Despite the many advantages for patients, laparoscopic surgery entails certain ergonomic inconveniences for surgeons, namely, loss of freedom during surgical maneuvers, deriving in an increased incidence of static postures, and adoption and maintenance of forced body postures for long periods of time. Since laparoscopic surgery became more advanced, operating time expanded and, in proportion, so did the levels of mental and physical stress imposed on the surgical team [1]. The combination of these factors with inadequate ergonomic design of surgical instruments may result in decreasing the surgeons' performance and accuracy, as well as the incidence of physical fatigue and musculoskeletal disorders.

The main technical limitations of laparoscopic surgery come from the technical modifications with regard to the open approach. Visual displays are located apart from the surgical field, affecting hand-eye coordination. Furthermore, bidimensional vision causes a confusing loss of depth perception. Specific instruments and fixed access ports limit movements and tactile feedback, worsening surgical performance and demanding greater muscular activity [2]. Design of laparoscopic tools implies a high degree of complexity, requiring manual skills and complementary new knowledge of how to use them. Design of surgical instruments and medical devices, as well as specific location of the monitor, operating table, foot pedals, and other surgical equipment determine to a large extent surgeons' postures while performing surgical procedures and the organization of the surgical team.

The introduction of laparoendoscopic single-site surgery (LESS) has led to a reduction of the number and size of incisions, thus providing aesthetical and emotional improvements to the patients. Positive results have been reported for this surgical approach with regard to postoperative outcomes, recovery time, length of hospital stay, and related costs [3]. LESS inherits the constraints of conventional laparoscopic surgery, adding new technical challenges. Working through a single port implies a defective triangulation, even more lack of coordination, external and internal instrument clashing, forced hands approximation with restrained manipulation, narrowing of the operative field, and possible pneumoperitoneum leakage [4]. Therefore, the use of LESS approach leads to a greater physical and mental workload for the surgeons [5, 6].

Robotic surgery is an increasingly expanding technology that uses human-machine interfaces providing solutions to laparoscopic constraints through enhanced dexterity, maneuverability, stability, and accuracy. Several studies reported lower complication rates and blood loss than conventional laparoscopic surgery [7]. This technology has been also integrated with LESS, and even more complex procedures by means of flexible access devices [8]. The main limitations of robotic surgery are high expenses and maintenance costs, difficulty to use it in low-volume or low-income centers, required experience from the surgical team, and instruments replacement [9].

The term ergonomics can be defined as the scientific study of humans at labor. The main objective of this field is to adapt environments to workers, improving equipment, workplaces, productivity, and training [10]. In this respect, ergonomics applied to laparoscopic surgery is focused on instruments' design and ergonomic assessment, surgeons' posture and workload

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analysis, surgical environment, and visual displays development [11, 12]. The main objective of this chapter is to review and analyze the ergonomic conditions during laparoscopic surgery and novel minimally invasive surgical approaches such as LESS and robotic surgery, as well as to establish ergonomic guidelines for laparoscopic surgical practice. In order to reach more representative information, studies published after 2010 and with over 20 subjects will be taken into account, excluding the review articles. The content of this chapter will be organized in three main sections: general ergonomic aspects in laparoscopic surgery, methods and technologies for ergonomic assessment in surgery, and ergonomics in minimally invasive surgical approaches.

2. General aspects

In laparoscopic surgery there are some primary ergonomic risk factors for the surgeon such as the body posture, the organization of the work space in the operating room (OR), and the design of the surgical tools.

2.1. Body posture

Laparoscopic surgery has changed the way surgeons interact in the operating field, what is revealed by a change in their posture and movements mainly of the upper limbs. In laparoscopic surgery dexterity is limited due to the fixed access port position, determining the angle of the instruments and instruments motion. Degrees of freedom are restricted from 36 in open surgery to 4 in laparoscopic surgery. This limited range of action leads to surgeons to acquire static, forced, and awkward long-term postures. The primary risk factor for the appearing of musculoskeletal disorders is body deviation from the neutral position. The ideal position for the laparoscopic surgeon is characterized by the arms slightly abducted, retroverted, and rotated inward at the shoulder level; the elbow should be bent at a 90–120° angle; the hands should grasp the instruments with the wrist slightly extended and with the distal interphalangeal joints almost extended, and the metacarpophalangeal and proximal interphalangeal joints flexed at 30–50°; fingers should be abducted and the thumb should be opposed to the index finger [13, 14]. Surgical team and equipment location in relation to the patient also must be considered. Likewise, lower body position can be non-ergonomic, provoking physical stress. Surgeons usually perform long procedures standing with a potential loss of stability and limited possibilities to change their body weight, especially when foot pedals are used [15].

2.2. Working environment

The workplace organization means that every individual member of the surgical team has appropriate space and access to all equipment. A lack of balance between the surgical staff and OR components can lead to work overloads and injuries. The advances in the field of laparoscopy are reflected in the development of optics with higher resolution and improved operational instruments. However, this progress has not always been accompanied by an ergonomic upgrade, which would alleviate some of the problems experienced by laparoscopic surgeons. Besides, some considerations have to be taken into account when using the laparoscopic equipment before and during surgical procedures.

2.2.1. The monitor

The visual information from the surgical scenario is provided by a monitor, which should be adjusted prior to the surgery to avoid undesirable postures for a long period of time. In the horizontal plane, the monitor should be straight ahead of the surgeon and in line with the forearm–instrument motor axis. In the sagittal plain, it should be positioned lower than the surgeon's eye level to avoid neck extension. The most comfortable viewing direction is approximately 15° downward. Viewing distance is highly dependent on monitor size. It should be far enough to avoid extensive accommodation of the eyes and contraction by the extraocular muscles, and close enough to avoid staring and loss of detail [16, 17]. To accomplish precision tasks, the use of an additional monitor near the operative field is recommended, as it improves hand-eye coordination [12, 17].

2.2.2. Operating table

The operating table must be adapted to the surgeon's height and position (standing or sitting). If the operating table is placed too high, muscles apply considerably more contraction force in order to raise and hold the shoulders as well as the elbows. If that position is maintained for a period of time it leads quickly to shoulder muscles fatigue. The table's height should be adjusted in such a way that laparoscopic instrument handles are slightly below the level of the surgeon's elbows. The proper table location keeps shoulders down, and the angle between the lower and upper arm is between 90° and 120° when performing manual work [18, 19]. Lifts can be used in case the table cannot be lowered to a certain height.

2.2.3. Foot pedals

Foot pedals are commonly used during laparoscopic surgery to activate instruments such as electrocauterization, ultrasonic shears, bipolar device, or other tissue welding/dividing instruments. They are often poorly positioned and could demand awkward and unnatural postures. Their main problems are the lack of visual control, unbalanced position of the surgeon, and use of too many pedals during laparoscopic surgery. A possible solution could be replacing them with hand controls when possible. Pedals should be placed near the foot and aligned in the same direction as the instruments, toward the target quadrant and laparoscopic monitor. This allows surgeons to activate the pedal without twisting their body or leg. A pedal with a built-in foot rest is preferable [20].

2.2.4. Surgical instruments

The performance of laparoscopic procedures and the position of surgeon's arms, hands, and fingers are highly dependent on the design of surgical instruments, mainly on the shape of the handle and the tool length. The non-ergonomic designs of handles that are not adapted to the shape and size of the surgeon's hand may lead to discomfort, paresthesias of the digital nerves and muscle fatigue [13]. Surgical instruments should enable surgeons to minimize the wrist flexion and rotation and ulnar deviation, keeping both arms at the sides of their body, and avoiding pressure points on their hands and fingers. Design of instrument handle should be according to the task to be performed, pistol-type handle for tasks that required force and precision-type handle for tasks that require precision [20].

3. Methods for ergonomic assessment

3.1. Body posture

The analysis of the interaction between the surgeon and surgical environment is a determinant factor to evaluate the ergonomic suitability of the working environment and provides crucial information to establish its basic design features. Traditional methods to assess surgeon's postures associated with a specific surgical activity have been based on observation techniques (photogrammetry) by observing the subject directly or using a recorded video [21, 22]. However, assessment methods have evolved and currently it is possible to perform and ergonomic analysis in the OR and using more automated technology. In this section, different methods of ergonomic assessment will be described based on kinematic analysis, muscle activity, or mental stress.

Figure 1. Motion tracking system based on retro-reflective markers. Artificial markers are placed on the targeted segments of the surgeon's body (*left*). A software application computes the kinematics variables during the task execution (*right*).

3.1.1. 3D motion tracking

These measurement systems quantify human movements by means of positional data obtained from artificial markers or sensors placed on the subject's body. Optical tracking techniques are based on color or retro-reflective markers that are identified at the three-dimensional space by a set of cameras [23] around the working space (**Figure 1**). However, these markers may have some occlusion problems in crowded spaces such as the OR, mainly because of the surgical staff and equipment. Another technology for motion tracking is the use of inertial sensors to record in real time the different body segments for subsequent kinematic analysis (**Figure 2**). These inertial measurement units are not affected by visual occlusions, and thus are appropriate for working environments as the OR.

Figure 2. Motion tracking system based on inertial sensors embedded in an elastic suit (*left*). A biomechanical model of the subject is created in real time (*right*).

A set of kinematics variables such as translational and rotational positions, velocities, and accelerations can be computed using the recorded positional data of the subject. Afterwards, the surgeon's posture can be analyzed with standard evaluation techniques such as Rapid Upper Limb Assessment (RULA) method or Ovako Working Analysis System (OWAS). Youssef et al. [24] compared variations in the surgeon's standing position during a virtual reality-simulated laparoscopic cholecystectomy using RULA score. They obtained better ergonomic posture for the between-standing technique, regardless of whether one- or two-handed technique. 3D kinematic analysis was used to differentiate joint variability between conventional laparoscopy and LESS [21], evaluating the influence of the upper body to the head stabilization.

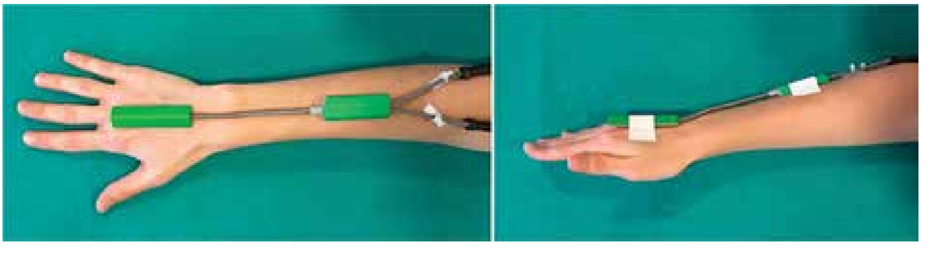

Figure 3. Placement of an electrogoniometer on the hand to record the wrist flexion-extension and radial-ulnar deviation.

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3.1.2. Electrogoniometers

Electrogoniometers are devices whose measurement signals (typically electrical voltages) are related directly to flexion-extension or rotation between body segments. These devices should be precalibrated to relate the measured voltage with the angles described by the analyzed joint (**Figure 3**). However, this measurement technology may be difficult to use for certain body segments. Besides, the need to be attached to the body segments and the use of wires for power supply make these devices a cumbersome solution to be used during laparoscopic practice.

3.1.3. Data gloves

Surgical tasks and instruments directly affect the surgeon's wrist and hand position. Data gloves allow for recording movements of the fingers and wrist by means of electromechanical technology or conductive sensors. In the clinical field, these devices have been used in conjunction with virtual reality systems for rehabilitation purposes [25] and surgical planning applications [26]. Recently, this technology has been used to analyze the surgeon's hand movements while using different surgical instruments during laparoscopic practice [5, 8, 11, 27] (**Figure 4**).

Figure 4. Motion capture data glove CyberGlove® (CyberGlove Systems, San José, CA, USA). This device consists of a series of conductive sensors with resistance flows sensitive to flexion variations.

3.2. Electromyography

Electromyography (EMG) measures the electrical signal associated with the activation of the muscle. This technique allows us to assess the electrical activity of a muscle group during the performance of a task. For data acquisition, electrodes should be placed following standard recommendations, as the surface EMG for noninvasive assessment of muscles (SENIAM) project [28], to ensure the acquisition of EMG signals and reduce potential artifacts.

Several metrics of muscle activity during the execution of a certain task can be computed by analyzing the EMG signal such as the percentage of the maximal voluntary contraction (MVC) [29], the amplitude probability distribution function (APDF) [30], or the muscle fatigue [6]. EMG has been an extended ergonomic assessment method in laparoscopic surgery to analyze the surgeon's postural muscle activity [5, 11], the use of different surgical instruments, and instrument handles [27, 31] (**Figure 5**).

Figure 5. Placement of the EMG electrodes on the right biceps brachii and forearm extensors (*left*). Use of the surface EMG to analyze the muscle activity of the upper body during laparoscopic practice (*right*).

3.3. Force platforms

Force platforms (single or multiple) are used to analyze the body balance during static or dynamic situations. These systems provide information about ground's reaction force against the force exerted by the subject's legs while supporting the body weight. Fan et al. [32] presented an alternative position to conventional flank position in retroperitoneoscopic urological practice. Body balance was assessed during simulated surgical tasks using two separate force plates (Wii Fit balance boards, Nintendo Inc.). They concluded that relative loading between feet was more balanced using the purposed posture.

3.4. Mental workload

Apart from the physical effort, psychological burden of surgeons performing laparoscopic procedures is reported higher in comparison to open surgical techniques [15]. For mental workload assessment, subjective techniques are the most extended methods. The National Aeronautics and Space Administration Task Load Index (NASA-TLX) evaluates six domains: mental demand, physical demand, temporal demand, effort, performance, and frustration during each task execution. A surgery-specific version of the NASA-TLX called SURG-TLX was presented and validated in 2011 [33]. Apart from the physical, mental, and temporal demand, this index assessed the task complexity, the situational stress, and distractions. Studies reported LESS is significantly more demanding than the conventional approach [34]. Training has been proved to improve both task performance and workload in laparoscopic practice [35].

3.5. Questionnaires

Questionnaires are another assessment tool that focuses on gathering information from a population of surgeons. Taking into account studies with at least 100 respondents, a survey

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to laparoscopic urologists in China concluded that most of them were not aware of the ergonomic guidelines for the OR [36]. Shoulder, neck, back, and hand pain and stiffness were reported as the main physical symptoms during laparoscopic procedures [36, 37]. The surgeon's height, glove size, age, gender, type of instrument, foot pedals, and height of the operating table have been identified as important factors for increasing the musculoskeletal pain symptoms [38–41]. The shape of the laparoscopic instrument handle was identified as the main element that needed to be improved [40].

4. Ergonomics in laparoscopic surgery

A summary of the results from the scientific literature regarding ergonomics in laparoscopic surgery are presented in **Table 1**.

Study	*N*	Task	Assessment method	Results
[12]	24 novices	Peg transfer with different monitor conditions	NASA-TLX	There are no differences among monitor positions in terms of perceived workload
[16]	20 novices	Suturing on simulator with ergonomic (G1) and normal (G2) settings	Photogrammetry: Neck, shoulder, elbow, and wrist	Optimal ergonomic setting leads to better task performance
[24]	32	Cholecystectomy on virtual simulator with variations in standing position and hand technique	RULA NASA-TLX	Better ergonomic posture for the between-standing technique [30]
[30]	25	Open, laparoscopic, and endovascular procedures	EMG: Back, neck, and shoulder	Open surgery imposes greater physical demand on the neck muscles compared with endovascular and laparoscopic surgeries
[42]	26: 13 with training of the non-dominant upper extremity and 13 without training	Eye-hand coordination task	EMG: Back, shoulder, and forearm	Training the non-dominant upper extremity leads to better alternated use of forearm muscles
[43]	100	Laparoscopic renal procedures with and without foot gel pad	Subjective criteria	The use of foot gel pads improves surgeon comfort and ergonomics during laparoscopy
[44]	28 novices	Nissen fundoplication model	NASA-TLX	Higher mental workload is associated with poorer laparoscopic performance

N: Number of subjects or cases.

Table 1. Reported results for ergonomics in laparoscopic surgery.

In a study with 30 surgeons with different experience in laparoscopic surgery, we analyzed the surgeon's muscle activity in back and forearm muscles during laparoscopic dissection and suturing tasks [29]. Percentage of the MVC of the trapezius, forearm flexors, and forearm extensors muscles was used for assessment of the muscle activity (**Figure 6**). Results showed that the surgeons with a higher degree of laparoscopic experience exhibited a lower level of muscle activity when compared with the novice surgeons. In another study with 50 surgeons, we analyzed the surgeons' hand spatial configuration during the use of two laparoscopic instrument handles, axial and ring-handled [11]. Movements of the surgeon's hand and wrist were recorded by a data glove and the level of wrist disorder was computed by a modified version of the RULA method [27] (**Figure 6**). Results showed that axial-handled needle holder entailed a more ergonomic posture for the wrist joint.

Figure 6. EMG and data glove data acquisition during the performance of laparoscopic tasks on simulator.

5. New surgical approaches

New surgical approaches have been presented to improve surgical outcomes and aesthetics results of patients. However, in some cases these surgical alternatives lead to an increase in technical and ergonomic challenges for surgeons that should be analyzed and identified.

5.1. Laparoendoscopic single-site surgery (LESS)

A summary of the results from the scientific literature for ergonomics in LESS are presented in **Table 2**.

In a study with experienced laparoscopic surgeons we assessed the surgeons' ergonomy during LESS, comparing it with conventional laparoscopic approach [5]. Surgeons performed a dissection tasks on a physical simulator using straight laparoscopic scissors and dissector for the conventional approach, and articulating tip scissors and dissector for the LESS approach (**Figure 7**). Ergonomic assessment was carried out by analyzing the muscular activity, and wrist and hand motion. Results showed that the LESS approach required greater level of muscular activity in the trapezius and forearm extensor muscles, but better wrist position compared with traditional laparoscopy.

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Study	*N*	Task	Assessment method	Results
[34]	48: 25 with LESS and 23 with conventional approach	Cholecystectomy	SURG-TLX	LESS cholecystectomy is more stressful and physically demanding than the conventional approach
[45]	24 premedical college students	Peg-transfer with two articulated and one straight graspers	EMG: Forearms. Electrogoniometers: Wrist. SURG-TLX	The straight instrument requires less muscle activation and wrist deviation
[46]	100 procedures: 50 triportal vs. 50 uniportal	Video-assisted thoracic surgery	Photogrammetry: Head NASA-TLX	Surgeons maintain a more neutral body posture during uniportal VATS, but with greater frustration
[47]	90 patients	Laparoscopic pull-through Soave procedure: conventional, LESS and hybrid approach	Subjective criteria	The conventional and hybrid approach have the same maneuverability and are less challenging than the LESS approach
[48]	175 patients	Different urological procedures	Subjective criteria	The use of conventional laparoscopic instruments is ergonomically feasible and safe in LESS procedures

N: Number of subjects or cases.

Table 2. Reported results for ergonomics in LESS.

Figure 7. EMG and data glove data acquisition during the performance of hands-on simulator tasks using a LESS approach.

5.2. Robotic surgery

Research has demonstrated the benefits of robotic surgery for the patient such as smaller incisions, reduced blood loss and postoperative pain, and reduced durations of in-patient care. Robotic platforms such as the da Vinci system (Intuitive Surgical Ltd., Sunnyvale, CA, USA) have been presented as a potential solution to the limited ergonomics in laparoscopic surgery.

In a study with surgeons with different levels of experience in robotic surgery, physical and cognitive ergonomic workloads using robotic-assisted and conventional laparoscopy were assessed during the performance of different basic laparoscopic training tasks [49]. Physical workload was assessed by using EMG from back, shoulder, arms, and forearms muscles, and mental workload by means of NASA-TLX index. They concluded that physical and cognitive ergonomics with robotic assistance were significantly less challenging. Another study comparing the use of standard laparoscopy and robotic assistance during intracorporeal suturing on porcine Nissen fundoplication models, medical students reported a lower workload using the robotic assistance [50]. Similarly, Moore et al. [51] reported significantly lower workload and mental effort on the robotic system compared to conventional laparoscopic approach while performing an eye-hand coordination task. Besides, another study using standard laparoscopic tasks during five consecutive training sessions, surgeons (novices and experienced) reported a less frustration score during and after training sessions and higher good mood score using robotic assistance [52]. The Imperial Test Assessment Tool was use to evaluate the frustration level.

6. New surgical devices

In order to overcome some of the ergonomic limitations of laparoscopic surgery, new surgical devices and instrument designs have been developed. In this section, we will review these novel surgical devices presented in the scientific literature. Studies published after 2010 and with no limit of subjects will be taken into account, excluding the review articles.

Several authors presented novel prototypes of ergonomically designed handles for laparoscopic instruments. One example is the Intuitool® laparoscopic instrument (University of Nebraska, Lincoln, NE, USA), which includes an ergonomic handle and a redesigned grasper actuation mechanism in order to create a more comfortable and intuitive handle-tool interface [53]. Büchel et al. [31] also presented a laparoscopic instrument prototype with an ergonomic pistol handle (Volargrip; University Hospital of Trondheim and Surgitech Norway AS, Trondheim, Norway). They compared this tool with two conventional laparoscopic instruments with ring handles. Results showed that each handle except the new prototype caused pressure areas and pain. A pistol grip laparoscopic instrument with a rotatable handle piece was presented by Steinhilber et al. [54]. EMG of the arm and shoulder muscles and wrist's posture by means of a gravimetric posture sensor were used to compare this novel instrument with the use of a conventional laparoscopic handle during the performance of a hand-eye coordination task. Results showed that the novel handle design did not decrease the biomechanical stress of the analyzed muscles, but neutral position of the wrist was more

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often. Yu et al. [55] compared a prototype laparoscopic grasper with three adjustable handle angles to a conventional instrument during the performance of Fundamentals of Laparoscopic Surgery tasks. Motion tracking and NASA-TLX were used to measure the surgeon's posture and workload. They concluded that the adjustable handle angle laparoscopic tool can reduce ergonomic risks of musculoskeletal strain and allows versatility for tasks alternating between positions.

Another possibility to improve the ergonomics in laparoscopy is by increasing the instrument's degrees of freedom. This is the case of the Radius Surgical System (Tuebingen Scientific Medical GmbH, Tuebingen, Germany), which provides two additional degrees of freedom (deflection and rotation of the tip) and enables the surgeon to manipulate the instrument accurately and precisely in an ergonomic position [56]. This manipulator has been successfully used to treat cases of esophageal achalasia and gastroesophageal reflux disease [57].

Apart from laparoscopic surgical instruments, other support devices have been developed to improve the ergonomic conditions during surgery. This is the case of operating chairs [58] or arm supports [59], whose main objective is to improve the surgeon's ergonomic posture during surgery. A novel portable ergonomic simulator for training of basic laparoscopic skills was also presented by Xiao et al. [60].

6.1. Handheld robotic instruments

New handheld robotic systems have been developed for laparoscopic surgery and single-site surgery to deal with some of their technical and ergonomic limitations. They provide precision-driven and articulating instrument tips, which increase the triangulation, and therefore improve the performance of some surgical maneuvers. One example of these systems is Jaimy® (Endocontrol, Grenoble, France), which provides two additional degrees of freedom controlled by a joystick placed on an ergonomic handle [8]. This handheld robotic instrument was ergonomically compared by means of surgeon's posture and muscular activity analysis with a conventional needle holder during the performance of basic laparoscopic training tasks. Results showed that the use of the robotized needle holder improved the surgeon's posture when compared to the traditional laparoscopic instrument.

The Kymerax™ (Terumo Europe NV, Leuven, Belgium) and DEX™ (Dextérité Surgical, Annecy, France) are other examples of handled robotic instruments for laparoscopic surgery and LESS. We have analyzed the ergonomics of these two surgical devices and compared it to conventional laparoscopic instruments by means of motion tracking, EMG of back, shoulder, and arm muscles, and data glove motion analysis (**Figure 8**). A positive learning curve in performance and ergonomics using the handheld robotic instruments has been reported. There were no differences in surgeon's muscle activity using the robotic and the conventional laparoscopic instruments, except for the biceps muscle. The robotic instruments led to an ergonomically more acceptable posture of the shoulder, elbow, and wrist. We believe that a period of adaptation should be required for this new technology.

Figure 8. Setup for the ergonomic study in the training environment using (left) the Kymerax™ and (right) the DEX™ handheld robotic instruments.

7. Conclusions

Laparoscopic surgery entails a limited range of movements, which leads to acquire static, forced, and awkward long-term postures. The primary risk factor for the appearing of musculoskeletal disorders is body deviation from the neutral position. The ideal position for the laparoscopic surgeon is characterized by the arms slightly abducted, retroverted, and rotated inward at the shoulder level; the elbow should be bent at a 90–120° angle; the hands should grasp the instruments with the wrist slightly extended. Results from the scientific literature showed that ergonomics during the laparoscopic surgical practice is related to the level of experience. Better ergonomic conditions during surgery lead to an improvement in task performance. Objective ergonomic analysis concluded that laparoscopic instruments with axial handel entail a more ergonomic posture for the wrist joint compared to a ring handle. Regarding ergonomics in LESS, studies reported that this surgical approach is more physically demanding than conventional and hybrid approaches. LESS approach requires greater level of muscular activity in the back and arm muscles, but leads to a better wrist position compared with traditional laparoscopy. Physical and cognitive ergonomics with robotic assistance were significantly less challenging when compared to conventional laparoscopic surgery. Further studies with a greater number of subjects should be done in order to obtain clear evidence-based findings of ergonomics during minimally invasive surgery.

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Chapter 6

Diagnostic Laparoscopy for Abdominal Tuberculosis: A Promising Tool for Diagnosis

Arshad M. Malik

Additional information is available at the end of the chapter

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Abstract

Introduction: Abdominal tuberculosis has plagued the mankind over several decades and is a major reason of morbidity and mortality even today in the developing world. It's a difficult problem to diagnose as most patients present with vague and nonspecific symptomatology. This study was performed with a view to find out an efficient and practical tool for diagnosing this problem.

Methods: This analytical descriptive study including 283 patients of abdominal tuberculosis is a continuation of an earlier study by the author in the same context. The study was conducted to highlight the usefulness of diagnostic laparoscopy in patients with vague abdominal symptoms, posing difficulty in establishing a conclusive diagnosis. The study extended over a nine-year period in a teaching hospital as well as some private hospitals. The data was collected and statistically analyzed on SPSS version 22.

Results: We had a total of 266 patients with unsettled diagnosis having vague abdominal symptoms. Out of the total study subjects, 214 (80.45%) were finally conclusively diagnosed to have abdominal tuberculosis on diagnostic laparoscopy. Abdominal pain is the most frequent symptom which makes the patients seek medical advice coupled with changing bowel habits, loss of weight and generalized weakness. Laparoscopy revealed various tuberculous lesions which were biopsied and diagnosed.

Conclusion: Diagnostic laparoscopy is a potential answer for the diagnostic dilemma posed by abdominal tuberculosis. Its efficacy and reliability need further studies in future.

Keywords: abdominal tuberculosis, diagnostic dilemma, morbidity, cost-effectiveness

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1. Background

Abdominal tuberculosis remains one of the commonest and most difficult diseases globally as far as the diagnosis is concerned [1–5]. It is also one of the common extra-pulmonary sites for tuberculous lesions. The disease may affect any part of the gut and may produce a chronic illness with vague abdominal symptoms or else may present in an acute obstructive form. The gravity of this problem is further increased by the vague and totally non-specific symptomatology [6–7]. The presentation of abdominal tuberculosis always mimics many other conditions like inflammatory bowel diseases and other similar conditions [8–10]. This state of confusion usually leads to an undue delay in diagnosis and treatment plan and thus further increases the overall morbidity. A large number of these patients present with acute abdomen and are diagnosed on exploratory laparotomy only. This actually has been a practice in our setup where a large number of patients undergo unnecessary laparotomies. These laparotomies could be easily avoided had there been an efficient and reliable method to diagnose abdominal tuberculosis. This actually led to the consideration of diagnostic laparoscopy in all patients with suspected abdominal tuberculosis to find out tuberculous lesions and to take biopsy of any such foci. This proved to be a breakthrough with a very encouraging result [11–13]. The study focused on the possible role of laparoscopy to establish the histopathological diagnosis of tuberculosis in patients having a high degree of suspicion but we found it difficult to establish a concrete diagnosis. Early diagnosis and starting anti-tuberculous diagnosis and an early resort to the anti-tuberculous treatment can coma after morbidity can facilitate an early recovery and an early return to work. This has a lot of benefits to the patient, the community and a major cut short on the health facility.

1.2. Pathology and pathogenesis

Tuberculosis is a common problem in developing countries like Pakistan, India, Bangladesh, etc. In the early 1990s, it was considered a lethal disease as there were no medications effective against the tubercle bacillus. With the advent of anti-tuberculous drugs, the disease is no more a problem as it used to be in the past. The disease represents one of the most dreaded forms of extra-pulmonary disease and can affect virtually all parts of the GIT including intestines and various abdominal viscera.

The portal of entry of mycobacterium into the GIT is through ingestion of the infected sputum, via blood, or there may be a direct spread from infected contiguous organs like fallopian tubes, etc. [14]. The abdominal tuberculosis is divided into the following categories based on the gross appearance and involvement of the target tissue.

A. Intestinal tuberculosis

B. Glandular tuberculosis

C. Peritoneal tuberculosis

D. Solid organs

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Rathi et al. [15] claim that abdominal tuberculosis constitutes 11% of the extra-pulmonary sites and the commonest area affected is the ileocecal region. The intestinal tuberculosis usually has three gross pathological forms as under

a. Hypertrophied

b. Ulcerative

c. Stricturous

The ileocecal tuberculosis is always a hypertrophied lesion which may present with acute intestinal obstruction. The ulcerative lesion is in the form of mucosal ulcers which usually present with diarrhoea and other abdominal symptoms. There is a recent claim that the extra-pulmonary manifestations of tuberculosis are observed with increasing frequency in Immuno-suppressed patients and more so with HIV patients as an accompaniment of the chronic illness [16]. An early diagnosis is the key to a curable non-operative treatment as a vast majority of these patients can be treated by anti-tuberculous drugs and thus can be saved from an undue laparotomy. In order to achieve this goal, the first and the foremost thing is to have a high index of suspicion about this entity [17] coupled with expertise in the laparoscopic technique.

2. Methods

This analytical descriptive study was conducted in a teaching hospital as well as some private hospitals. The study subjects attended the outpatient department with acute or chronic presentations. Patients having a totally confusing symptomatology and vague symptoms where a firm conclusive diagnosis could not be established were included in the study and were informed about the purpose of the study and the possible outcome. Having learnt the objectives of the study, only those who gave their consent were enrolled and admitted in the hospital. Patients who were already diagnosed as ileocecal tuberculosis or were on anti-tuberculous treatment were excluded. Upon arrival, the initial management was totally determined by the mode of presentation. Patients with acute presentation were resuscitated with I/V fluids and decompressed by nasogastric suction to stabilize for intervention. The patients who presented with vague abdominal symptoms were thoroughly examined and were given conservative treatment to correct body fluids and electrolytes and to relieve pain.

After having done the initial resuscitation and management, investigations were sent including blood complete picture, chest x-ray, abdominal x-rays, ultrasound examination and CT scan in some patients. Failing to achieve a conclusive clue on abdominal examination and investigations, a diagnostic laparoscopy was planned, keeping in view a very high incidence of the tuberculosis in our part of the world. The various variables studied included demographics, clinical presentations, common laboratory results and outcomes of diagnostic laparoscopy.

3. Results

Of the total study subjects, 266 patients were chosen for diagnostic laparoscopy based on the fact that their findings and symptomatology were so vague that a conclusion could not be drawn from the clinical examination and the usual laboratory workup. The demographics included 186 (70%) males and 80 (30%) females with a mean age of 36.59, range of 48 (17–65) and a standard deviation of 10.875. The main symptoms and the mode of presentation of the patients are shown in **Table 1**. The minimum duration of the symptoms was found to be eight days (3%), while the maximum duration of symptoms was found to be > 1 month (43%). A vast majority (81%) of the patients were found to have haemoglobin < 10 G%. Ultrasound examination was not a very helpful tool as depicted in **Table 2**. The Mantoux test was positive only in eight (3%) patients while 97% had a negative Mantoux. Erythrocyte sedimentation rate (ESR) was raised in a high number of patients (97%). Generalised tenderness of abdomen and weakness was present in 88% of the study population, while the remaining patients had insignificant examination findings. Chest x-ray was absolutely normal in 250 (94%) of the total study subjects. The various laparoscopic findings are shown in **Table 3**. One hundred and seventy-eight (67%) patients had a positive history of taking off and on anti-tuberculous medication prescribed by the local general practitioners. Most of the patients, referred from far flung areas, referred from remote far flung areas had positive laparoscopic findings compared to the urban population ($p < 0.001$). Of the total population, we were able to confirm histopathological diagnosis in 259 patients having different forms of abdominal tuberculosis. The various tuberculous findings on laparoscopy are found in **Figures 1–3**. Stricturous pathology and obstructive ileocecal tuberculosis needed operative intervention in 23 (9%) patients while remaining patients received a full course of anti-tuberculous drugs and showed full recovery. A follow-up of these patients was carried for a period of three years.

	Main symptoms			
	Sub-acute intestinal obstruction	**Vague abdominal pain and loss of weight**	**Chronic off-and on-obstruction**	**Total**
Mode of presentation				
Acute	0	0	12	12
Chronic	2	180	0	182
Acute-on-chronic	66	0	6	72
Total	68	180	18	266

Table 1. Mode of presentations and main symptoms.

	Frequency	**Percentage**	**Total**
Inconclusive	150	56	
Diagnosed tuberculosis	34	12.78	266
Gave suspicion of tuberculosis	82	30	

Table 2. Ultrasound abdomen results.

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Finding	Frequency	Percentage
No abnormality detected	52	19
Miliary tuberculosis found	104	39
Mesenteric lymphadenopathy detected	90	34
Intestinal strictures found	20	7.5

Table 3. Various laparoscopic findings.

Figure 1. Miliary tubercles on the intestinal wall and abdominal wall.

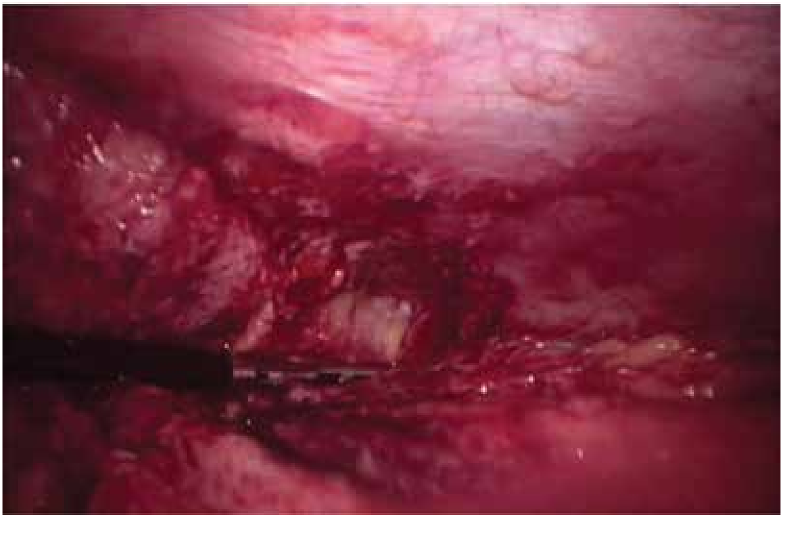

Figure 2. Plastic adhesions.

Figure 3. Ascitic fluid.

3.1. Difficulties and limitations

Although apparently an excellent diagnostic tool for the diagnosis of abdominal tuberculosis, at times we faced a lot of problems especially when there are severe plastic adhesions and more so when you find an abdominal cocoon. It is usually very difficult to introduce the first trocar in such situations.

4. Discussion

Abdominal tuberculosis remains a difficult major health issue all over the world. It is highly challenging and a dreaded problem for surgeons working in far-flung remote areas with limited resources and facilities. It is a diagnostic challenge for surgeons globally but more so in the third-world countries where the disease is rife and remains unnoticed till it turns into a serious emergency. The abdominal tuberculosis is known for its varied and confusing symptomatology whereby it mimics closely with various other similar diseases like inflammatory bowel diseases [18–19]. The unusual presentation and confusion in diagnosis usually lead to unnecessary and avoidable laparotomies, which is most of the time performed as a last resort to reach to a conclusive diagnosis. Contrary to the earlier reports, the developing countries are showing a fearful increase in the incidence of abdominal tuberculosis, as reported in recent studies [20–22]. The increase in the prevalence of abdominal tuberculosis in the developing countries is attributed to a rising incidence of HIV-positive population linking it to immunosuppression [12, 19].The age incidence of our study population coincides with other similar reports [20]. The male dominance is very clear in our studies as reported by other similar studies [18]. The varied presentation is the hallmark of abdominal tuberculosis, and as

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shown in our results, it is also consistent with and reported by other similar reports [23–24]. Our study highlights the fact that there is a very alarmingly high incidence of this disease in the poor, underprivileged rural population of Sind province of Pakistan. It is highly recommended to have a high level of suspicion to reach a conclusive diagnosis whenever a patient presents with vague abdominal symptoms [25]. There is hardly any absolutely reliable diagnostic test that can give a 100% confirmed diagnosis of abdominal tuberculosis. This simply is the reason for an unnecessary and life-threatening delay in the diagnosis of this disease [8, 26]. The diagnostic laparoscopy and biopsy of the tuberculous lesions are not a recent advancement but are rather known for over 30 years now [27]. It however has not been practiced widely and as commonly as it should have been. Even today, this diagnostic tool has not attracted the desired level of attention and usually is considered a last resort rather than the first in difficult diagnostic situations. In the current study, we gave it a place of primary investigation tool along with other diagnostic tests and we found it extremely encouraging as the yield of diagnosis is over 80%, in line with other similar studies [28–29]. Diagnostic laparoscopy prompts the diagnosis and can reduce the delay which can increase the morbidity and can lead to unnecessary laparotomies while improving the outcome [30–31]. Despite all the benefits, some limitations like a deceiving view leading to mis-diagnosis regardless of the experience of surgeon are mentioned by few studies [32–35].

5. Conclusion

The diagnostic laparoscopy in suspected cases of abdominal tuberculosis is an efficient and rewarding method of diagnosis. A regular use of this diagnostic modality can improve the overall outlook of this common disease in the developing world.

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Laparoscopic surgery developed as the most element change ever in the history of surgery. The approach of this method is no more a late headway. The history goes back three decades now when appendectomy was initially performed laparoscopically in 1983. It was then polished by not very many specialists, and there was a moderate move of the method from traditional open surgery to laparoscopic surgery. Hesitance to take in an absolutely new method, absence of facilities, and appropriate training were main considerations ruining its direction. After an underlying hindered period came a sudden ascent in the worldwide preoccupation of the consideration toward this novel strategy. There was an aggregate move from open to laparoscopic surgery in a large portion of the focuses with an expanding rundown of operations being performed laparoscopically.

This book is intended to bring forward the very many advancements in the field of laparoscopic surgery. There are many valuable contributions from eminent laparoscopic surgeons ranging from diagnostic to therapeutic procedures performed by this technique. I hope it will benefit the trainee surgeons as well as the experienced alike. Suggestions and positive criticism are more than welcome.

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