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Laparoscopic surgery: A qualified systematic review

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Abstract

AIM: To review current applications of the laparoscopic surgery while highlighting the standard procedures across different fields.

METHODS: A comprehensive search was undertaken using the PubMed Advanced Search Builder. A total of 321 articles were found in this search. The following criteria had to be met for the publication to be selected: Review article, randomized controlled trials, or meta-analyses discussing the subject of laparoscopic surgery. In addition, publications were hand-searched in the Cochrane database and the high-impact journals. A total of 82 of the findings were included according to matching the inclusion criteria. Overall, 403 full-text articles were reviewed. Of these, 218 were excluded due to not matching the inclusion criteria.

RESULTS: A total of 185 relevant articles were identified matching the search criteria for an overview of the current literature on the laparoscopic surgery. Articles covered the period from the first laparoscopic application through its tremendous advancement over the last several years. Overall, the biggest advantage of the procedure has been minimizing trauma to the abdominal wall compared with open surgery. In the case of cholecystectomy, fundoplication, and adrenalectomy, the procedure has become the gold standard without being proven as a superior technique over the open surgery in randomized controlled trials. Faster recovery, reduced hospital stay, and a quicker return to normal activities are the most evident advantages of the laparoscopic surgery. Positive outcomes, efficiency, a lower rate of wound infections, and reduction in the perioperative morbidity of minimally invasive procedures have been shown in most indications.

CONCLUSION: Improvements in surgical training and developments in instruments, imaging, and surgical techniques have greatly increased safety and feasibility of the laparoscopic surgical procedures.

Key words: Laparoscopic surgery; Endoscopic surgery; Pancreatic surgery; Rectal resection; Gastrectomy; Gastric cancer; Colon resection; Appendectomy; Esophagectomy; Cholecystectomy

Core tip: This review investigates different applications of the laparoscopic approach on the basis of the current literature and summarizes studies concerning laparoscopic surgery in the different medical fields.

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INTRODUCTION

Laparoscopic surgery has existed since the development of diagnostic laparoscopy in the 1960s. The pioneers of laparoscopic surgery Semm K[1] and Muehe E[1] changed it from a diagnostic to a surgical procedure at the beginning of the 1980s, and it has since become a frequently applied technique for a wide field of indications. The procedure has become the gold standard for many organ systems, with some of the most common being reproductive (particularly gynecological) and digestive (as for cholecystectomy). Significant improvements in surgical training, as well as developments of instruments, imaging, and surgical techniques, have made laparoscopic surgery safe and feasible across different medical fields.

This review summarizes studies on the laparoscopic surgery across different fields and highlights the state of the art, standard procedures in laparoscopic surgery.

MATERIALS AND METHODS

A comprehensive search was undertaken using the PubMed Advanced Search Builder. The exact search strings are listed in Tables 1 and 2. In addition, publications were hand-searched in the Cochrane database and in the high-impact journals such as *Ann Surg*, *Lancet*, *BMJ*, *Brit J Surg*, *World J Gastroenterol*, *Surg Endosc*, *World J Surg*, *Am J Gastroenterol*, *Hernia*, *Am J Surg*, *Langenbecks Arch Surg*, *Arch Surg, Chirurg*, *J Am Coll Surg*, and *Colorectal Dis*. Publications had to meet the following criteria to be selected: review articles, randomized controlled trials, or meta-analyses discussing the subject of laparoscopic surgery (Figure 1). A total of 403 articles were identified and downloaded for full-text review. Of these, 218 articles were excluded for not matching the inclusion criteria and 185 articles were determined to match the search criteria and included in the analysis.

The systematic review was conducted in compliance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines[2]. The study was registered on the PROSPERO international prospective register of systematic reviews (Registration Number: CRD42015019334).

RESULTS

Appendectomy

The systematic reviews and meta-analysis that compared the clinical outcome of laparoscopic *vs* open appendectomy clearly showed an advantage of the laparoscopic procedure[3]. Laparoscopic appendectomy has been proven to be a safe and feasible procedure in the treatment of acute appendicitis and even complicated appendicitis[4,5]. Supporters of the laparoscopic appendectomy maintain that in addition to an improved diagnostic accuracy, the procedure lowers the number of wound infections, results in less pain, faster recovery, and an earlier return to work[6]. However, there seems to be an increase in the operating time for the laparoscopic *vs* open surgery[7]. Earlier reviews reported an increase in incidences of intra-abdominal abscess in the laparoscopic group[8]; later reviews, however, did not find any significant difference between the laparoscopic and open surgery groups[6]. The authors explained the discrepancy in the data as a result of an adapted learning curve, better instruments and imaging quality, and of course more experienced surgeons[6].

Regarding the complication rates of laparoscopic *vs* open appendectomy, there were no significant differences in the overall postoperative complications, pulmonary complications, or postoperative ileus[3]. Considering the postoperative ileus situation after a laparoscopic appendectomy, a significant reduction in the short-term bowel obstruction in pediatric patients and patients with perforated appendicitis were described.

Regarding the long-term bowel obstruction or bowel obstruction requiring surgery, there was a significantly better outcome in the laparoscopic appendectomy group[9]. Patients who underwent the laparoscopic procedure for their appendectomy had shorter hospital stays and were able to "return to normal activity" and "return to work" faster than those who underwent open surgery[3]. The initial higher charges and operating costs in the laparoscopic group were compensated through reduced costs required outside the hospital stay[10].

In the obese patients, the outcome parameters, wound infection rate and overall postoperative complication rate were significantly decreased compared to the open appendectomy group. The operation time did increase, most likely due to technical challenges associated with patients who have a body mass index > 30 kg/m^2. Despite this, the advantages of the laparoscopic approach outweigh the disadvantages for the treatment of appendectomy in obese patients[11].

In pregnant patients, there is a higher risk of fetal loss (although with little evidence) and a slightly increased rate of preterm labor, which was not significant and was without clinical importance[12].

Table 1 Search strategy using publication within the past 5 years

	And	And	And	And	Results	Selected
Laparoscopic surgery	Pancreatic surgery	Whipple	Meta-analysis	Analysis	1	1
Laparoscopic surgery	Rectal resection	Meta-analysis			37	13
Laparoscopic surgery	Gastrectomy	Gastric cancer	Meta-analysis		65	20
Laparoscopic surgery	Liver resection	Liver surgery	Meta-analysis		30	11
Laparoscopic surgery	Colon resection	Meta-analysis			16	6
Laparoscopic appendectomy	Open appendectomy	Meta-analysis			26	13
Laparoscopic surgery	Esophagectomy	Meta-analysis			9	3

Table 2 Search strategy using unrestricted publication dates

	And	And	And	Results	Selected
Laparoscopic surgery	Open cholecystectomy	Meta-analysis		61	15
Laparoscopic surgery	Endoscopic surgery	Groin hernia	Meta-analysis	15	6
Laparoscopic surgery	Endoscopic surgery	Incisional hernia	Meta-analysis	19	6
Laparoscopic surgery	Fundoplication	Meta-analysis		42	9

Newer techniques of reduced ports surgery and single-incision surgery as a less invasive alternative are also performed as a procedure for laparoscopic appendectomy.

The reviews comparing single-incision *vs* conventional laparoscopic appendectomy show a significantly longer operation time with an outcome similar to a conventional laparoscopic procedure with no difference in wound infection rate, conversion to open surgery, reoperation, intra-abdominal collection of fluid, or overall complications[13,14]. Single-incision appendectomy is considered a safe and feasible procedure with comparable clinical outcomes when undertaken by experienced surgeons[15,16]. Results related to better cosmetics and an earlier return to work should be considered with caution due to the small number of studies reporting these two items, along with the short follow-ups used for evaluation of cosmetic results[17]. Critics of the approach have stated that there is no benefit in a single-incision access for appendectomy since clinical outcomes were related to increased operation time, higher frequency of technical failure, and potentially higher costs[18].

Cholecystectomy

Patients who underwent cholecystectomy *via* laparoscopic procedure had no significant difference in morbidity and mortality compared to those who underwent open surgery. In fact, they had faster recovery and shorter hospital stay[19]. Although mini-laparotomy had a similar overall outcome, the authors regard the minimalized open technique as a viable and safe option for healthcare providers without financial resources for laparoscopic equipment and without appropriate, trained surgeons[20]. Later studies showed no difference between laparoscopic and minimally open and conventional open surgery in terms of morbidity and mortality[21].

Laparoscopic cholecystectomy is proven as a safe and feasible technique; concerning cardiac and respiratory complications, it shows superiority over open surgery in elderly patients[22].

Patients with child A or B stadium of liver cirrhosis who underwent laparoscopic cholecystectomy had a similar or even better outcome than those who underwent open surgery. As a result, these patients experienced a lower incidence of postoperative complications[23], such as blood loss and bacterial contamination of ascites - an important cause of in-hospital morbidity and mortality[23]. The postoperative incidence of hepatic insufficiency was not different. These findings have to be regarded with caution, however, because some of the studies had small patient groups with heterogeneous patient populations and criteria[24].

The routine on-table use of intraoperative cholangiography shows no advantage in preventing injuries of the common bile duct or retained stones[25]. There is a significantly longer surgery time with the recommendation not to use routine on-table cholangiography when there are no clinical, radiological or biochemical signs of common bile duct stones[26]. In the management of suspected common bile duct stones, there is a slight advantage concerning complications after sphincterotomy in patients, where the endoscopic sphincterotomy is performed intraoperatively rather than preoperatively[27].

With laparoscopic cholecystectomy, the goal is to minimize trauma to the abdominal wall as much as possible by using the upcoming techniques of reduced port[28-30] or single-port surgery[31] or hybrid NOTES techniques. These techniques have yet to prove their feasibility, safety, and possible superiority over the established 4-port technique of laparoscopic cholecystectomy. In the case of single-incision techniques, the findings varied depending on the number of cases included in the studies. Some of the earlier studies that had been performed when single-incision surgery was newly introduced often lacked evidence and were thus biased.

Some of the studies showed better postoperative pain scores after single-incision procedure *vs* laparoscopic

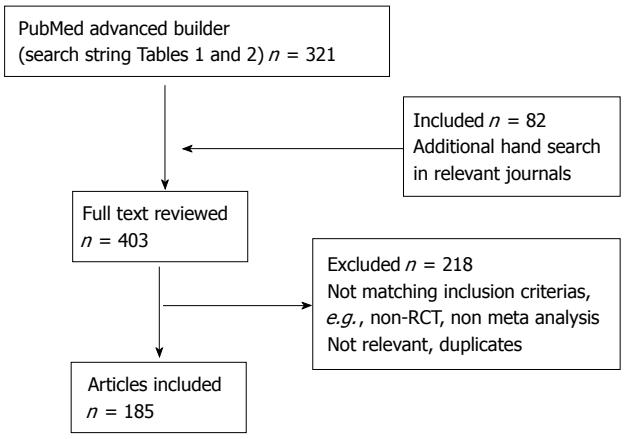

Figure 1 Selection of articles for the review.

procedure[32,33], while others showed no difference[34,35]. Because there was no significant difference in mortality, morbidity, short-term surgical outcome, length of hospital stay, or return to normal activity, many authors consider single-incision cholecystectomy safe and feasible, with a better outcome for patients' cosmetic satisfaction. Others do not recommend single-incision techniques because there is no apparent advantage over conventional laparoscopic cholecystectomy, which has longer operation times and requires additional ports[36]. Hybrid NOTES did not differ in overall complications, surgery-related complications, or postoperative pain, but did have a significantly better outcome in "return to normal activity"[37].

Laparoscopic cholecystectomy is accepted as the gold standard, although studies have shown that mini-laparotomy is similar in outcome, with decreased surgery time and lower cost[19,21]. Single-incision techniques and hybrid NOTES must prove their advantage or similarity in the same way that laparoscopic cholecystectomy has had to do.

Esophageal surgery

Minimally invasive surgery for esophageal cancer is a technically challenging procedure, and the great variability in surgical techniques makes it difficult to interpret the findings and outcomes reported in the current literature. Many studies have a small number of patients, and no randomized controlled trials are available to verify the data[38].

Patients with esophageal cancer who underwent laparoscopy experienced longer surgery time, less blood loss, shorter hospital stay, and reduced overall morbidity[39,40].

One of the difficulties in comparing results across different studies was a lack of definitions regarding postoperative complications or operative techniques. Many studies did not perform or describe a radical lymphadenectomy, and lymph node harvest was lower than the recommended minimum number[41]. Other studies have found a similar lymph node harvest[42] or even more lymph nodes in laparoscopic treatment compared with open surgery[43]. The reported minor complications associated with laparoscopy were similar to open surgery, but the major complications were significantly lower in the laparoscopic group. The lower number of harvested lymph nodes showed a similar percentage of positive lymph nodes, and the lymph node harvest did not impact the survival rate[44], even in the case of the long-term results[45]. A reported adjustment in the surgical techniques (the "Ivor Lewis approach") led to better short-term and long-term outcomes for patients undergoing minimally invasive surgery with an acceptable lymph node harvest and a similar oncological outcome to open surgery[46,47].

Burdall *et al*[48] found significant independent parameters that had an impact on outcome in overall survival. These included the use of neoadjuvant chemotherapy, tumor size (T3 or T4), positivity of lymph nodes, R1-resection, and the surgical approach. Overall, patients who underwent laparoscopic treatment had a significantly better overall survival.

Reflux surgery

The laparoscopic approach has become the gold standard for surgical management of gastroesophageal reflux disease (GERD). Laparoscopic surgery in the treatment of GERD led to reduced hospital stay, faster recovery, faster return to normal activity, and a significant reduction of perioperative morbidity compared with open surgery[49,50]. Laparoscopy has been shown to more effectively treat symptoms, such as reduction of heartburn and regurgitation, and patients reported higher quality of life than achieved with other medical treatments such as proton-pump inhibitor drug alone[51].

The different surgical techniques in the surgical management of GERD are still under discussion. The functional outcome appears similar whether the short gastric vessels are divided or not; therefore, this step in the reflux surgery procedure seems unnecessary and may reduce the operation time if avoided[52-54]. Posterior surgical techniques - the Nissen 360° and Toupet 270° procedures - gave patients a satisfactory control of reflux symptoms. Dysphagia symptoms were more prevalent after the Nissen procedure, while Toupet operations had a higher rate of gas-related symptoms, such as inability to belch and bloating[55]. The Toupet's procedure seems to have superior level 1a evidence than the Nissen procedure. However, these findings should be taken with caution since the study had a Jadad score of 2 with a corresponding possibility of bias[55]. Another evidence-based appraisal for these posterior methods in reflux surgery showed adequate symptom relief after both procedures with a slightly reduced rate of adverse results in the Toupet group[56].

The anterior approach in the treatment of GERD often leads to a longer esophagus acid exposure time, persistent heartburn symptoms and a higher rate of reoperation in the short-term outcomes compared with the posterior approach. However, these symptoms are counterbalanced by the less severe dysphagia

symptoms. For the long-term outcomes, persistence of heartburn and higher use of antacids prevail, with dysphagia scores and gas-related symptoms being similar to those in the posterior group. Hence, there is level 1a support for the usage of posterior techniques in reflux surgery[57].

Robotic surgery used in surgical treatment of GERD is a feasible alternative to laparoscopic surgery. The approach has similar results in terms of symptom relief and surgical outcome. However, lack of obvious advantages with respect to operating time and length of hospital stay and cost do not support the expansion of robotic surgery to other applications in clinics[58].

Gastric surgery

Laparoscopic gastric surgery is a demanding procedure. Results of the surgery depend on the stage of the gastric tumor (early *vs* advanced), whether a partial or total gastrectomy was performed, and presence of gastrointestinal stromal tumors (GIST)[59]. Laparoscopic resections have an overall better short-term outcome with less blood loss, shorter hospital stay, faster recovery of bowel movement with shorter time to first flatus, and fewer serious perioperative complications. However, there was an overall longer time for surgery[60]. Wound complications and surgical site infections were less significant in the laparoscopic group. For severe postoperative complications, such as anastomotic leakage, stenosis, bleeding and postoperative ileus, there was no difference from open surgery[61].

Clearance of harvested lymph nodes is an important factor influencing long-term survival in gastric cancer. Laparoscopic distal gastric resection for early gastric cancer shows fewer or a similar amount of harvested lymph nodes compared with open surgery[60,62,63]. Viñuela *et al*[64] had significantly more lymph nodes harvested in the open surgery group, and the proportion of patients with < 15 lymph nodes was similar to that in the laparoscopic group. The authors were of the opinion that adequate pathological lymph node staging was not compromised by the laparoscopic technique.

Further improvements in the laparoscopic technique show no difference between D2-lymphadenectomy performed for advanced gastric cancer compared to open surgery[65,66]. The surgical approach is not the only parameter that determines the types of or frequency of complications, as well as an acceptable long-term outcome. Other factors such as patient's age, comorbidities (*e.g.,* chronic liver disease, chronic renal failure) and additional organ resection have a significant effect on complications and outcome[67].

In advanced gastric cancer, the total laparoscopic gastrectomy consistently showed the advantages of laparoscopic surgery, having a better short-term outcome than open surgery. Incidence of the short-term complications appears to be correlated with intraoperative blood loss; hence, many studies directed their attention to this parameter. The results in all studies were consistently in favor of the laparoscopic surgery[68].

Concerning the long-term follow-up, the results of laparoscopic surgery were suggested to be similar to open procedures[69]. Current clinical evidence showed that laparoscopic gastric surgery is not inferior to open techniques, even in the treatment of advanced gastric cancer, if the surgeon is experienced[70]. The laparoscopic gastric resection had acceptable results concerning oncological safety[71]. These findings were confirmed in gastric stromal tumors. Laparoscopic surgery was superior to open techniques regarding short-term postoperative outcome without compromising oncological safety and long-term oncological outcome[72]. Furthermore, these long-term results depended mainly on the tumor itself rather than the performed surgical technique[73].

The results of robotic gastric surgery are comparable to laparoscopic surgery. The robotic gastric surgery could be favorably effective considering the increased number of harvested lymph nodes and D2-lymphadenectomy in patients with high body mass index[74]. Data on the long-term outcome and survival are rare, so randomized clinical trials are required[75].

Colorectal surgery

Laparoscopic colorectal surgery is well established as a safe procedure and must be differentiated between the surgical treatment of the benign and malignant disease. The review of current literature shows an ongoing learning curve and an improvement in the management of post-operative care, such as developing fast-track concepts and pathways in "enhanced recovery after surgery" (ERAS). This combination of the surgical procedures (minimally invasive access) reducing major morbidities and standardized postoperative treatment concepts led to a satisfying outcome for patients undergoing colorectal surgery[76]. Colorectal cancer patients who underwent laparoscopic surgery within a multimodal rehabilitation protocol experienced the shortest hospital stay and the lowest morbidity[77].

The general benefits for patients undergoing laparoscopic surgery are the minimal trauma of access, reduced pain, accelerated postoperative return of bowel function, faster return to activity, and better cosmesis. Evidence for potential benefits such as reduced adhesions and a lower rate of incisional hernias was difficult to find[78].

For the ulcerative colitis surgery, the results showed a reduced morbidity in colectomy with a lower mortality in the laparoscopic group compared to open surgery[79].

Surgical treatment of Crohn's disease showed a trend towards lower rate of wound infections, with a lower rate of reoperation in non-disease related complications in the laparoscopic group[80]. In regard to the perioperative morbidity and convalescence, there is evidence that laparoscopic surgery is favored over open surgery for the treatment of Crohn's disease. The data on the lower incidence of small bowel obstruction

and Crohn's recurrence following a minimally invasive surgery was of poor quality[81].

A laparoscopic surgical approach to diverticular disease was associated with longer operation time and reduced postoperative pain. In the elective cases, the reported quality of life score and reduced major morbidity rates were superior to open surgery[82-84]. The decreased incidence of wound infection, the lower need for blood transfusion, and the lower ileus rates led to acceptance of laparoscopic surgery in treatment of elective cases of recurrent diverticulitis[85]. Although laparoscopy minimized the short-term complication rate, a meta-analysis of randomized clinical trials found 42% morbidity in the elective cases, a worrisome finding[86].

The use of hand-assisted devices led to a decrease of conversion rates without difference in the duration of surgery or complication rates. However, all these studies had methodical limitations, along with the additional cost associated with these devices[87]. These findings were less certain in the case of emergency surgery. In generalized peritonitis due to perforated diverticulitis, the approach to drain without resection reduced the incidence of Hartmann's procedure without increasing morbidity and mortality. This finding may lead to a shift in the management of acute perforated diverticulitis in the future[88].

Natural orifice specimen extraction after colon or sigmoid resection is feasible and seems to have an advantage in minimizing trauma to the abdominal wall by avoiding a small incision for specimen extraction. Current literature, however, shows that this technique is not standardized, and no pooled analysis or meta-analysis is practicable, so evidence in the literature is weak[89].

Colon cancer

For colon cancer, the laparoscopic approach is regarded safe and feasible without compromising the oncological outcome. The short-term outcome benefits were lower blood loss, earlier recovery of bowel movement, earlier resumption of oral intake, and reduced hospital stay, as well as lower overall morbidity. The lymph node harvest and results of oncological outcome were similar to open surgery. Thus, laparoscopic surgery was considered superior to open surgery in the short-term outcome of colon cancer[90].

Expert opinion in the literature shows a growing acceptance of laparoscopic surgery for treatment of colorectal cancer, which is further supported by the large randomized clinical trials[91]. Evaluation of the long-term outcomes for non-metastatic colon cancer shows no difference in the occurrence of port site metastasis/wound recurrence, cancer-related mortality, tumor recurrence, or overall mortality[92]. Considering the anatomical circumstances and the oncological outcome, complete mesocolic excision is also recommended in the minimally invasive surgery[93].

For the right hemicolectomy, in regard to the benign and malignant disease, the intraoperative and postoperative results were favorable for the laparoscopic group. There was no difference between the laparoscopic treatment and open surgery in regard to the short-term oncological outcome, including lymph node harvest and length of specimen, and the long-term oncological outcome[94].

In transverse colon tumors, the evidence is not as clear as in other types of colorectal cancer. The benefits of the laparoscopic approach have been demonstrated; however, the data need to be interpreted with caution due to the heterogeneity in the included studies[95].

For long-term survival following laparoscopic colectomy, there was no difference in the overall survival between the laparoscopic group and open surgery. Large randomized controlled trials (excluding transverse colon cancer) demonstrated that laparoscopic surgery was not inferior to open surgery in the long-term oncological outcomes[96]. There was no significant difference in overall mortality, total recurrence rate, or 5-year disease-free and overall survival[97].

Conversion to open surgery seems to have a worse oncological long-term outcome than completion with laparoscopic surgery or starting with an open procedure from the outset. Factors for conversion include higher body mass index, male sex, T3-T4 tumor size, or positive lymph nodal disease[98].

Robotic surgery has short-term outcomes similar to laparoscopic surgery. For blood loss, conversion rate, and time to recover bowel function, there were significant findings in favor of robotic surgery compared with laparoscopy[99].

Rectal surgery

The current data is insufficient to favor a certain technique over another for treatment of rectal prolapse. Laparoscopic rectopexy had fewer postoperative complications and a shorter hospital stay compared with open surgery. The different rectopexy fixation methods did not differ in their outcomes[100]. Compared with a perineal approach (Delorme procedure), the laparoscopic group had higher overall morbidity[101].

Rectal cancer

Rectal cancer laparoscopic surgery has the benefit of minimally invasive access. In the laparoscopic group, blood loss, time to first bowel movement, intake of oral fluids and wound infection were significantly lower after the laparoscopic approach. There were no differences between the laparoscopic approach and the open surgery in terms of complications such as ureter injury, urinary retention, ileus, anastomotic leakage, or an incisional hernia. Oncological outcomes in the short-term and long-term results, such as length of specimen, circumferential resection margin, regional recurrence, port/wound metastasis and distant metastasis, also showed no significant difference[102]. Three-year, 5-year and 10-year

disease-free and overall survival was similar between the two treatments[103].

For early rectal cancer, preoperative staging determines the surgical approach to the rectum. In tumors with good prognostic features and a limited risk of relapse, which can safely be removed while preserving the rectum, the endoscopic mucosal resection or a transanal microsurgery can be performed. If local excision is pathologically difficult or risky, a complete total mesorectal excision (TME) must be done. The laparoscopic approach showed a better short-term outcome with a similar oncological outcome[104].

Contrary to the findings for colon cancer, the clinical outcome was not worse when a laparoscopic procedure was converted to open surgery in rectal cancer. The conversion had no impact on unplanned hospital readmission or redo surgery, nor on 3-year disease-free survival and local recurrence compared with a laparoscopic procedure[105].

Minimally invasive TME can also be performed safely and efficiently after neoadjuvant radiochemotherapy, with a rate similar to open surgery for postoperative complications and a comparable rate of positive circumferential resection margin[106].

Considering postoperative bladder and sexual function in patients undergoing rectal surgery for cancer, there is no difference between the laparoscopic and open surgery group for men in the postoperative ejaculatory and erectile function or bladder function. No difference in the sexual or bladder function between open and laparoscopic surgery was found in women either. Therefore, none of the techniques are superior to the other. Since there is limited data available for these results, they must be viewed with caution[107].

The oncological outcome in laparoscopic surgery was controversial when laparoscopic TME was first introduced. However, the latest results that focus on equivalent oncological outcome prove this topic. The involvement of a circumferential resection margin is equivalent to open TME. Harvest of lymph nodes in the open surgery group was described as slightly higher without having an impact on oncological outcome. In subgroup analysis, there was no difference in R0-resection, distal margin clearance, integrity of the mesorectal fascia, or in local recurrence after 5 years[108,109].

Laparoscopic rectal surgery is a challenging procedure for experienced surgeons. For trainees being supervised by an experienced surgeon, there are similar rates of anastomotic leakage with no difference in the conversion, R0-resection, local recurrence and 30-d mortality compared with experienced surgeons. Furthermore, there were no differences in the cancer-specific survival between the experienced group and the supervised trainees. Therefore, the procedure can be performed by supervised trainees with an adequate learning curve[110].

An upcoming technique is a transanal approach for performing the TME in combination with a laparoscopic approach. In the current literature, the reported TME quality with intact mesorectal fascia is satisfactorily complete, and the number of harvested lymph nodes was $\geqslant$ 12, so the oncological safety parameters seem to be adequate[111].

Robotic procedures in the rectal surgery show the known merits of robotic surgery with a favorable perioperative outcome considering the conversion rate. There were no significant differences with laparoscopic surgery in terms of surgery length, blood loss, recovery of bowel movement, hospital stay, short-term complications and details on the pathological performance such as harvested lymph nodes, resection margin, and circumferential resection margin. These results must be viewed with caution, however, because most of the studies had small sample size or a low level of evidence[112-114]. More high-quality studies are necessary to show the benefit of robotic over laparoscopic surgery and to justify its costs[115]. The long-term benefits of robotic surgery in colon and rectal cancers are still unknown[116].

Liver surgery

Laparoscopic resection of the liver is performed mainly when treating metastasis of colorectal carcinoma or primary hepatocellular carcinoma. Other indications such as cyst resection are rare. The minimally invasive approach is widely applied to patients with limited disease, such as those with solitary findings of 3-4 metastases in the liver. Findings in the liver segments Ⅱ-Ⅳ are better suited for a laparoscopic approach than those in segments Ⅶ, Ⅷ and Ⅳa, which are difficult to reach. Detailed preoperative imaging and an intraoperative ultrasound are helpful[117].

Laparoscopic liver resection has advantages for short-term outcomes such as lower blood loss with a lower rate of transfusion, shorter postoperative hospital stay, and lower rates of positive resection margin and perioperative complications. Patient selection may have influenced some of the observed outcomes[118].

Left lateral resection is described as safe and feasible, and due to lower complication rates and the known advantages of minimally invasive access, some authors claim that it should be used as a standard technique for left resection. At this time, however, there is a lack of randomized controlled trials to support such a statement[119].

Laparoscopic resection with positive short-term results and improved surgical outcome[120] do not compromise oncological outcome or 5-year disease-free and overall survival compared to patients with similar results from open surgery[121,122].

There were fewer postoperative complications in the laparoscopic group concerning short-term outcomes of hepatocellular carcinoma resection, positive resection margin rate, and tumor recurrence, with no significant difference between laparoscopic and open surgery. In short-term results, no tumor recurrence in the site of resection margin and no peritoneal dissemination or

trocar site metastasis were found in the laparoscopic group[123].

The incidence of postoperative ascites and liver failure in the laparoscopic surgery group was lower, benefiting patients with severe liver disease and especially for those with hepatocellular carcinoma[124]. For laparoscopic surgery in the treatment of liver cirrhosis, the advantages for the short-term and long-term outcomes persist[125]. Although laparoscopic liver resection is described as a safe and feasible alternative to open surgery, with favorable outcomes, there is a need for future randomized controlled trials[126] as the current studies do not provide enough support[127].

The laparoscopic approach for radiofrequency ablation is used for hepatocellular carcinoma. Intraoperative laparoscopic ultrasound led to an oncological upstaging in up to 32% in a small case series[128]. In the laparoscopic resection of liver metastases for colorectal carcinoma, these findings do not show any true benefit for the patient, so here, laparoscopy as a diagnostic method appears more as a useful instrument when a peritoneal disease is suspected[129].

Blood loss with a significant reduction of transfusion and the overall complication rate were lower in the laparoscopic group. No difference in the long-term oncological results in 1-, 3- and 5-year survival was found compared with open surgery[130,131]. Some analyses even showed a lower incidence of R1 resection in the laparoscopic group[132].

Resection of liver metastasis can be performed synchronously with colectomy, with a favorable outcome of the short-time results, but there was no difference in the long-term results in regard to the survival or recurrence. The authors consider synchronous resection of liver metastasis to be an option for selected cases, but the included studies lacked standardized inclusion criteria, so the results must be interpreted carefully[133].

In fenestration of congenital hepatic cysts, a favorable short-term outcome of the laparoscopic approach is described without a difference in postoperative complications or cyst recurrence rates, so the minimally invasive surgery is favored in these cases[134].

In living donor liver transplantation, the laparoscopic approach is seen as comparable to the open approach for liver procurement in terms of donor safety. Lower blood loss was shown in the laparoscopic group[135].

Surgery of the adrenal glands

Minimally invasive surgery of the adrenal glands has become the gold standard in resection of benign and malignant disease. Potential laparoscopic techniques are the lateral transperitoneal approach and the posterior retroperitoneal approach. Regarding outcome of these approaches, compared to each other, the posterior retroperitoneal seems to be a comparable[136] or superior[137] approach based on the operation time, blood loss, pain score, hospital stay, and time to return to normal activity[138]. The conversion rate and surgical complication rate are similar[139]. Both techniques have replaced open access to the adrenal gland in tumors $\leqslant$ 8 cm. For the retroperitoneal approach, the findings support a faster convalescence compared with the lateral transperitoneal approach. Since the difference is not significant the authors could not make a recommendation for either approach[140].

Minimally invasive adrenalectomy is the mainstay of operative options for adrenal tumors. Despite lack of evidence for the technique in the randomized controlled trials, it has gained acceptance in the surgical world. Adrenalectomy is performed in hormone-active tumors, lesions > 4 cm, and benign disease with untypical imaging[141].

Studies have shown that the laparoscopic approach can be an acceptable option for the primary neoplasm or adrenal metastasis with no evidence of local invasion[142]. If there is any doubt before the operation that the tumor cannot be removed with an intact capsule, open surgery must be considered[143].

Surgical therapy of primary aldosteronism (Conn's disease), compared with medical treatment, leads to a significantly better decrease in blood pressure, with no difference in the cardiovascular complications in qualitative analyses with heterogeneous protocols. Despite the absence of randomized controlled trials, there is support for unilateral resection of unilateral disease[144].

For subclinical Cushing's disease, unilateral laparoscopic adrenalectomy can resolve the hypercortisolism with low morbidity and can provide significant benefit to blood pressure, glucometabolic control and obesity *vs* a conservative medical treatment. However, these findings lack evidence are from studies that include data that is too low quality for a systematic review, so the authors could not give a definitive recommendation[145].

In the treatment of refractory Cushing's disease, bilateral adrenalectomy plays a crucial role in cases where transsphenoidal surgery of ACTH-producing tumors does not lead to normalization of hypercortisolism. In these cases, laparoscopic bilateral resection is safe and effective[146].

The single-incision technique showed similar benefits to the conventional laparoscopic approach. The studies found no difference in blood loss, length of hospital stay, or time to oral intake, with similar outcomes in cosmetic satisfaction, rate of complication, rate of conversion to open surgery, and need for transfusion[147]; longer duration of surgery, lower pain perception, and slightly faster recovery were also reported[148].

Robotic surgery is used in the retroperitoneal posterior and transabdominal lateral approach. A significantly lower blood loss was found in the robotic group compared with the group who underwent laparoscopic surgery, with no difference in the short-term surgical outcomes or complications[149]. With longer surgery and selection of patients, the widespread robotic techniques will be difficult[150] even with lower conversion rate for large tumors compared with laparoscopic surgery[151]. Training and costs associated with the technique are the

major drawbacks of robotic surgery in the treatment of adrenal glands[152].

Pancreatic surgery

Laparoscopic surgery of the pancreas is a challenging procedure for experienced surgeons. Most of the studies had a small sample size, and patients were highly selected. Laparoscopic left-side resection of pathologies of the distal pancreas or laparoscopic enucleation for benign lesions has been reported as safe and feasible, with morbidity comparable to open surgery[153]. Left-side resection is the most common laparoscopic procedure in pancreas surgery because it is technically easier to perform. The duration of surgery, surgical morbidity, rate of R1-resection and rate of major complications like pancreatic fistula are similar to the open surgery group; hospital stay and blood loss were reduced[154]. Long-term outcomes of the left resection are equivalent[155] even for malignant findings[156].

For laparoscopic necrosectomy, therapeutic drainage is the best option for conservative management. The literature findings were difficult to compare because of differences in the techniques used, as well as in timings of the interventions[154].

Laparoscopic pancreaticoduodenectomy is performed as a laparoscopic-assisted or total laparoscopic procedure[157]. The outcomes were comparable to open surgery in overall morbidity and surgical-related complications; oncological criteria were fulfilled in terms of number of harvested lymph nodes and resection margin. Due to a lack of randomized controlled trials and the small sample sizes of highly selected patients[158], there was a selection bias so the results should be viewed with caution[154].

Robotic surgery was reported only in the case reports or cohort series, making it difficult to compare. Trials were heterogeneous so data could not be analyzed. In the selected patients, results were comparable to laparoscopic surgery[159] with a trend to improve spleen preservation[160].

Surgery of the spleen

Laparoscopic surgery has become standard for splenectomy in elective cases. The laparoscopic approach showed a reduced morbidity, especially in the pulmonary complications after surgery and wound infection compared with open surgery[161].

In large spleens, a hand-assisted device showed an advantage to open surgery in terms of reduced pain and reduced length of hospital stay, with a surgical outcome similar to laparoscopic surgery. Furthermore, compared with laparoscopic splenectomy, the hand-assisted surgery of the spleen had a lower conversion rate to open surgery[162].

Information on the alternative methods of access like NOTES or single-incision laparoscopic splenectomy is rare. These methods are feasible, however, there is a high risk of bias in the early case reports regarding the alternative approaches in highly selected patients[163]. Only single cases on robotic surgery for splenectomy have been reported[164].

Laparoscopic hernia surgery

Groin hernia: Operative and perioperative management of hernia repair represent a wide field of surgical research. Of the tissue repair techniques, the Shouldice procedure is the only technique with recurrence rates that are lower than other open non-mesh techniques. Mesh repair is evidently superior to tissue reconstruction[165]. The Lichtenstein's procedure is the gold standard in open hernia mesh repair, and has minimal recurrence and morbidity.

There are two minimally invasive surgeries available for a groin hernia: A transabdominal preperitoneal repair (TAPP) and a totally extraperitoneal hernia repair (TEP). While the mesh is placed in the same position, the approach through the abdominal cavity (TAPP) or in front of the peritoneum (TEP) is different. Both techniques are described as effective treatments of a groin hernia but with a slight increase in perioperative morbidity in comparison to open mesh techniques[165].

Comparing the two techniques, TEP is associated with a slightly faster postoperative recovery; the TAPP technique has a significantly higher incidence of operative morbidity. For incidence of recurrence, long-term neuralgia, duration of surgery, and length of hospital stay, both laparoscopic approaches seem to be similar[166].

Comparison of the minimally invasive approach with the open mesh repair (Lichtenstein) in unilateral hernias, the TAPP technique had a similar recurrence rate and was associated with greater perioperative morbidity. The TEP technique had a slightly increased recurrence rate and a comparable incidence of perioperative complications. The minimally invasive techniques had a significantly reduced risk of chronic groin pain and groin stiffness[167]. In recurrent hernia repair, neither of the laparoscopic procedures were considered superior to open surgery in terms of recurrence and chronic pain[168].

Use of lightweight mesh in hernia repair reduced the risk of chronic groin pain[169] with no effect on recurrence[170] and showed a reduced risk of stiffness and groin body sensation[169,171].

The type of mesh fixation method in laparoscopic hernia repair led to different outcomes. Fibrin glue showed a reduced risk of chronic groin pain and a higher patient satisfaction[172] without impact on recurrence rate[173]. Use of staplers/tacks had a higher incidence of postoperative and groin pain[174].

In the TEP procedure, mesh fixation was not necessary. In cases where mesh fixation was not used, there was no difference in recurrence, incidence of seroma, or postoperative or chronic pain[175].

In the guidelines for endoscopic hernia repair, the EAES Consensus (European Association of Endoscopic Surgeons), and the International Endohernia Society recommend technical points for a tailored approach to

specific hernias on the basis of evidence[176-178].

Incisional hernia: Laparoscopic surgery for repair of an incisional hernia shows no difference in recurrence or length of hospital stay compared with open surgery. There were significantly fewer wound infections and complications requiring mesh removal[179]. Risk of bowel injury increased, while postoperative pain score showed no significant difference. Long-term results were not available from the current data[180].

A comparison of the data was difficult. There were many studies, reviews and meta-analyses regarding ventral hernia and incisional hernia, although the origin of these hernias was different. Furthermore, the optimal mesh was not found and neither was the optimal mesh fixation[181], which is why long-term results with a high level of evidence are not available[182].

The results on incisional hernia were highly biased due to methodical limitations. It was hard to distinguish whether patient-related factors or technique-related factors, such as type of mesh and fixation, influenced the outcome[183]. Compared with open surgery, there was a longer duration of operation with no difference in the short-term adverse events[184]. The incidence of wound infection was significantly decreased[185]. There was no difference in the overall recurrence. There was a lack of randomized controlled trials with a standardized technique to demonstrate one technique's superiority over the other[186].

DISCUSSION

Laparoscopic surgery has continuously developed over the past years, advancing from an invasive diagnostic tool to an efficient instrument for surgical treatment of benign and malignant disease. Ongoing training, experience, and development in imaging and laparoscopic instruments have facilitated extension of the applications of laparoscopic surgery.

The overall advantage of minimizing trauma to the abdominal wall has been reproducible in many of the laparoscopic procedures compared with open surgery. Faster convalescence, reduced hospital stay, and faster return to normal activity are the most evident advantages of laparoscopic surgery. The outcome, efficiency, decreased incidence of wound infections, and reduced perioperative morbidity of minimally invasive procedures have been shown across different applications, *e.g.,* cholecystectomy, fundoplication, and adrenalectomy. Despite the lack of randomized controlled trials to support laparoscopic applications, these procedures are accepted as the gold standard for surgical intervention. The laparoscopic surgeries are longer than the open ones. However, the duration has decreased over the years through experience and the learning curve. There has been no evidence that open surgery is superior to laparoscopic surgery in terms of oncological short- and long-term outcomes.

Interpretation of the data in meta-analyses or reviews was at times difficult. Different laparoscopic techniques were mixed up under one indication, *e.g.,* in incisional hernia repair. The use of different mesh and types of fixation led to heterogeneity in the compared studies. The possibility of bias as a methodical limitation was high.

Demonstrating the superiority of laparoscopy over other techniques, such as single-incision surgery, NOTES, and robotic surgery was difficult. Cost and effort were the major drawbacks in distribution of these techniques, particularly for the robotic surgery.

Randomized controlled trials in some fields of laparoscopic surgery could not be performed. There is a lack of sufficient evidence, because, for example, sample size calculation to achieve a certain power is too high to conduct such a study in daily surgical routine. There is a need for randomized controlled studies and standardization because many results were interpreted from case reports or cohort series, and were difficult to compare. This is especially needed in technically demanding procedures like laparoscopic gastric, pancreatic and esophagus surgeries.

COMMENTS

Background

Laparoscopic surgery is a technique with a widespread field of applications. In some medical fields, the laparoscopic approach is a standard, *e.g.,* cholecystectomy. Due to the continuous surgical training and the ongoing development of instruments, imaging systems and surgical techniques, highly complex laparoscopic procedures are possible, such as laparoscopic gastrectomy. The primary aim of this review is to show a variety of different laparoscopic surgeries and to assess their benefits and outcomes in benign and malignant diseases.

Research frontiers

This review is a clinical evaluation of laparoscopic surgery and its role in the surgical treatment of benign and malignant disease of different organ systems. Since the first laparoscopic appendectomy and the first laparoscopic cholecystectomy, there has been an overwhelming development of the technique. Therefore, this review shows a complete summary of the most frequent procedures used for digestive diseases and performed with a minimally invasive approach.

Innovations and breakthroughs

No other surgical technique has gone through such advances as laparoscopic surgery over the years, including approaches such as robotic or single-port surgery. This review summarizes the current literature (review articles, meta-analyses, and randomized trials) to give an overview of the laparoscopic procedures.

Applications

Laparoscopic surgery has become a state of the art technique in many fields of surgical treatment, providing better clinical outcomes than open surgery without compromising the oncological results.

Peer-review

The authors have performed a good study. The manuscript is interesting.

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