Technical considerations depending on the level of vascular ligation in laparoscopic rectal resection

M. Sokolov1 · B. Petrov1 · S. Maslyankov1 · K. Angelov1 · M. P. Atanasova2 · D. Tzoneva2 · P. Gribnev1

Received: 13 May 2020 / Accepted: 28 March 2021 / Published online: 19 April 2021
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Abstract

Aim In addition to ischemia there is also anastomotic ends tension proven to be a risk factor for anastomotic leak. HT vascular ligation is accepted as a rule, in attempt to achieve tension-free anastomosis. LT is a preferred option, based on the more accurate preservation of proximal intestinal segment microperfusion and lower risk of damage to the hypogastric plexus. The aim of this study is evaluation of comparative indicators in high tie (HT) and low tie (LT) laparoscopic rectal resections.

Methods A prospective nonrandomized comparative cohort study of patients in our department with cancer of the rectum in clinical stage I–III, operated on in laparoscopic approach over a 6-years period.

Results For the period 2015–2020, a number of 208 laparoscopic surgeries have been done for rectal cancer. Patients were divided into three groups—group A with HT vascular ligation 116 pts. (69%), group B—53 pts. (25%), underwent low ligation—LT and group C—39pts. (19%) low tie plus lymph node dissection of the apical LN group (LT-appic LND). The distribution was made without randomization, based on the operators’ expertise. Anastomotic leaks were 3.8% in group A, 3.0% in group B and 2.9% in group C (p > 0.05) with no significance difference. There is no significant difference in the number of lymph nodes obtained in group A and group B, while in group C the number of the harvested lymph nodes was higher (p < 0.05). The indicators for intestinal / defecation dysfunction, as well as for urinary/sexual dysfunction, according to our data, are significantly more favorable in patients with LT, in contrast to the other two groups.

Conclusion HT vascular ligation attempts to achieve tension-free anastomosis and more harvested lymph nodes. However, LT could be a preferred option, based on the lack of significant evidence for a difference in specific oncological survival and due to more accurate preservation of proximal intestinal segment microperfusion to prevent anastomosis dehiscence, also for its lower risk of damage to the hypogastric plexus. Splenic flexure mobilization provides elongation of the proximal intestinal segment, but has no proven effect on anastomotic leakage incidence. It increases surgical duration and is in fact necessary in up to 30% of the cases. At the present moment there is no precise data whether LT has an advantage in terms of prevention of autonomic nervous and urogenital dysfunction. New prospective randomized and highly probative studies are needed to standardize the procedures in specific clinical situations.

Keywords High tie · Low tie · IMA · Rectal cancer · Splenic flexure mobilization
Regarding the oncological expediency of the procedure, the scientists who are "PRO"-HT support the thesis that the removal of the apical group of lymph nodes located around the root of the IMA in the volume of resection provides a more adequate N—staging, which requires extraction of \( \geq 12 \) regLN \([3, 4]\). Surgeons which are “CONS”—HT have the opposite opinion, according to which Apical LN (+) rate is only 0.3–8.6% of the cases (Fig. 4). Moreover, in pT1 the apical-LN status is almost always (−) negative [5]. According to the Japanese Society for Cancer of the Colon and Rectum, the apical-LN status discussed in pT3 / T4 sigmoid cancer is 3.6% and pT3/T4-rectal cancer is only 5.1%. However, the presence of positive apical lymph nodes—pN3 (Apical LN (+)) in itself carries an “a priori” worse prognosis for the patient [6]. In addition, variations in lymphatic drainage of rectal carcinoma should be considered, although very rare, depending on its location. For example, in case of cancer located in the proximal third of the rectum might cause isolated metastases into the hepato-duodenal liga-ment [7] and a tumor of the distal third of the rectum can be spread by iliac LN (+) and lateral pelvic meta [8].

By anatomical point of view many surgeons accept the HT technique as no alternative approach in low rectal resec- tion, however, the proximal anastomotic segment could be protected against ischemia only by the intact LCA-IMA-aorta collateral mechanism thus relying only on the left branch of the MCA and its connection to the paracolic Drummond-artery through the vascular segment of Riolan.
In contrast, in LT adequate perfusion of the proximal limb is provided by the preserved LCA and the marginal Drummond artery [9–11]. An observational retrospective cohort study from 2020 shows that LT of the IMA in laparoscopic radical surgery of rectal cancer appears to be associated with a lower risks for anastomotic leakage, anastomotic stricture, and genitourinary dysfunction, a shorter hospital stay, and lower costs [12]. Other studies, some of which RCTs indicate that the level of ligation of the inferior mesenteric artery does not significantly affect the rate of anastomotic leakage, but rather the systemic hypotension and hypoperfusion in the early postoperative period could cause clinically significant hypoperfusion during the marginal artery, especially in patients with severe vascular atherosclerosis [13, 14]. An innovative solution to the problems in this direction could appear through the increasing penetration and use of the method for intraoperative assessment of microperfusion of anastomotic intestinal segments by intravenous application of fluorescent dye—indocyanine green (ICG) [15, 16].

To the impact of autonomic innervation in different approaches to IMA ligation and the associated effort for prevention of urogenital and anorectal dysfunction, anatomical studies indicate that 1 cm from the onset of IMA is a safe ligation area [17, 18], while another study found a dense network of autonomic nerve fibers up to 5 cm from the beginning of the artery along its initial part [19]. This brings additional ambiguity in the choice of level of vascular ligation.

Randomized clinical trial of defaecatory function after anterior resection for rectal cancer in 51 pts with HT versus 49 pts with LT shows that there is no conclusive evidence that the LT technique has a better prognosis with respect to intestinal function associated with autonomic innervation [20]. However, the results of the so-called HIGHLow Trial (RCT) conducted in 214 patients indicate that LT in LAR and TME gives better results in terms of genito-urinary dysfunction, without affecting the initial oncological outcomes—(p > 0.05) in oncological results and anastomotic insufficiency [21].

Regarding the securing and insuring of tension-free anastomosis formation at the sutured ends, which is the second major factor for anastomotic leakage, the ligation of IMV at the lower border of the pancreas provides insignificant elongation of the intestinal segment in LT group [22, 23]. Studies of Corder et al. [23] Pezim and Nicholls [24] have not established particular advantage concerning LT in providing sufficient critical length to the proximal intestinal segment as well. The question of providing satisfactory length of the proximal bowel segment, in addition to the level of vascular ligation, is directly related to the problem of splenic flexure mobilization (SFM) which could be: (1) Partial—medial or lateral approach, high or low tie of IMA, high ligation of IMV, mobilization of the descending colon, division of phrenicocolic and splenocolic ligament till the inferior pole of the spleen is clearly demonstrated, omentum detachment; (2) Complete—same steps than in partial and adds division of the pancreaticomesocolic attachments till the left branch of the middle colic artery including or not division of the gastrocolic ligament. That maneuver is needed routinely in order to avoid tension at the anastomotic sites in the anterior rectal resection. Opponents of this claim believe that this is technically more difficult itself procedure during laparoscopic surgery and there is lack of evidence about its actual effect on the elongation of the colon. Moreover, it is associated with a significant prolongation of operative time, an increase in intraoperative complications rate and a relatively small number of patients who would actually benefit from it [25]. Reddy et al. show that only in 50% of cases of LT with splenic flexure mobilization provides sufficient elongation of the proximal segment and actually they find that not in rectal resection, but in partial or total sigmoidectomy. However, the addition to this technique of ligation of the LCA descending branch enables a tension free anastomosis and is a particularly beneficial maneuver [26]. High quality anatomical cadaveric studies demonstrate achieving around 10 cm elongations by partial flexure mobilization, whereas in complete SFM the bowel elongation achieved is about 28 cm and more. Gouvas claims that additional mobilization of the splenic flexure along with high tie ligation provides tension-free anastomosis with sufficient vascularization but still without categorical influence on early postoperative

Fig. 4 Projection of the apical lymph nodes at the origin of IMA
complications, including anastomotic dehiscence [27, 28]. On the other hand, it substantially increases the duration of the surgery. One of the most recent published research on that subject is by Girard et al., demonstrating elongation of 9 cm in HT, compared to 3–4 cm in LT. Therefore, HT + SFM ensures that all types of colo-rectal/colo-anal anastomoses could be accomplished, and in addition there has no real effect on the immediate postoperative results (complications, including anastomotic leak), but on the other hand significantly prolongs the operative time [29]. The Singapore (2008) and Dublin (2007) studies show that the actual rate of need for SFM has been found in no more than 25%, respectively 28%, of the patients with anterior resection of the rectum with equal incidence of anastomotic leaks in patients with HT, with or without SFM [30].

As a summary, HT vascular ligation is accepted as a rule, in attempt to achieve tension-free anastomosis. LT is a preferred option, based on the more accurate preservation of proximal intestinal segment microperfusion and lower risk of damage to the hypogastric plexus. However, data from 1102 patients published by the meta-analysis and Trial Sequential Analysis of eight RCTs from the last year show that there is no significant difference between HT and LT of the IMA in terms of oncological outcomes or postoperative morbidity and mortality while potential confounding by the use of neoadjuvant and adjuvant therapy, disease stage, tumor size and location and protective stoma performance should be considered [31]. Although various technical nuances have been described in the generally well-standardized laparoscopic rectal cancer surgery, some surgeons in certain centers still exist, which for a variety of reasons do ligation at superior rectal artery level in rectal cancer. This definitely contradicts the modern oncology principles.

The recently prevailing Eastern approach to ligation just below the origin of the LCA combined with lymph node dissection (LND) around the origin of the IMA (low tie with LND) shows no significant differences with HT in terms of oncological prognostic parameters as it is anatomically less invasive and is not inferior to “high tie” with prognostic point of view [6].

The aim of this study is evaluation of comparative indicators in high tie (HT) and low tie (LT) laparoscopic rectal resections in connection with certain technical considerations.

**Methods**

A prospective nonrandomized comparative cohort study of patients in Department of surgery, University Hospital Alexandrovska, Sofia with cancer of the rectum. Patients were in clinical stage I-III, operated on in laparoscopic approach over a 6-years period. Only patients who underwent radical curative anterior resection of the rectum with a colorectal anastomosis were included. Patients have been stratified into two groups according to the level of ligation of the inferior mesenteric artery (IMA) and vein—group A—“high tie”—at the site of the origin (around 1 cm) from aorta and group B—“low tie”—distal to the origin of the left colic artery. Additional group C for the last year are patients with LT-apical LND. Splenic flexure mobilization has been performed after high tie ligation in almost all cases as a routine approach (92% of them). All patients underwent an air-leak test to verify the integrity of the anastomosis. The choice of operative approach was determined by the surgeon’s preferences and experience. Written informed consent was obtained and attached to the medical records from each treated patient. The primary end point as comparative indicator is the anastomotic leakage rate. The secondary end points are number of LN harvested, defecatory and GU function—evaluated using a standardized survey and uroflowmetric examination, duration of the operative intervention and intraoperative complications rate. The follow-up period was 12–48 months. All the data processing and analysis have been done by SPSS 18.0. Allowance to conduct the study was obtained from the institutional ethics committee, in accordance with the established rules.

**Results**

For the period 2015–2020, a number of 208 laparoscopic surgeries have been done for rectal cancer in whom a radical anterior resection of the rectum with curative intent was performed. The patient distribution was as follows: group A—116 (56%) high ligation of the IMA with SFM (Fig. 5) compared to group B—53 patients (25%) underwent low ligation (Fig. 6) and group C—39(19%) LT-appic LND (Fig. 7).

![Fig. 5 Intraoperative view of HT—ligation](image-url)
The patient demographic and clinical parameters are detailed in Table 1.

A number of 18 patients have been operated on in delayed emergency manner. The type of colorectal anastomosis in all cases is routinely an instrumental termino-terminal anastomosis with a circular stapler. Due to that reason the type and manner of preparation of the anastomosis is not perceived as a determining factor in the interpretation of the primary endpoint, i.e. anastomotic leakage. Gender distribution represents 56% male and 44% female. Anastomotic insufficiency was reported with increasing values of CRP and feculent secretion from contact drains in the period 3–9 POD. It is important to note that 51 patients (25% out of total of 208 patients) underwent low or ultra-low anterior resection of the rectum—34 of them are from group A (29.3% out of all in group A), 10 are from group B (18.8% out of all in group B) and the remaining 7 (18% from pts. in group C). In those patients the construction of a colorectal anastomosis was followed by the formation of a protective ileostomy for 6–8 weeks—in 84% of them and a transversostomy (6–12 weeks)—in the remaining 16%. This inevitably leads to misrepresentation of the results regarding the actual occurrence and detection of clinically significant anastomotic leaks due to tension forces in the area of the anastomotic ends as well as defecatory disfunction in the early postoperative period in those cases. However, the reported mean anastomotic leaks were 3.8% in group A and 3.0% in group B and 2.9% in group C (p = 0.418) indicating a lack of significant difference (Fig. 8).

The average duration of surgery in group A was 194 min, while in group B it was 133 min—p = 0.027, in group C—218 min (p = 0.04 comparing with gr.A and p = 0.01 comparing with gr.B) which represents a significant difference in those three studied target groups (Fig. 9).

The data on this indicator show a lack of clear dependence on the experience of the operator but a clear connection with the type of surgical approach—HT or LT. The additional performance of SFM in high vascular ligation—group A, as well as the meticulous dissection of the apical lymph/adipose tissue—in group C take more time, but this is compensated by the accumulation of surgical skills.

The average number of harvested lymph nodes varies in cases—n = 8–32. This depends very much on the experience and methodology used by the examining pathologist, as well as on his determination in the processing and examination of the specimen. Our data show that there is no significant difference in the number of lymph nodes obtained in group A—on average 15 ± 4; in group B—on average 13 ± 4, while in group C the number of lymph nodes harvested was on average 19 ± 3 (p < 0.05 compared to groups A and B) (Fig. 10).

Intraoperative complications were reported in 5 patients—2.96%. Only one of them is from group B (1.87%)—bleeding from IMA during dissection.
remaining 4 patients were from group A (3.45%)—in one lesion of the vascular hilus of the spleen, followed by splenectomy. In two others—parenchymal bleeding from the tail of the pancreas, controlled by imposed clips and bipolar coagulation. In the other two patients, a lesion of the colon was found in the area of the left flexure, which was overcome at one point by intestinal sutures. The data show significantly fewer intraoperative complications rate in group B and no intraoperative complication in group C in the last year.

Table 2 below presents the results of measuring the bowel dysfunction in patients from the three comparable groups.

The results show lower values of defecation dysfunction, respectively, slightly better results in the LT group compared to the other two groups, between which there is no significant difference in these indicators.

The urine bladder dysfunction was assessed using the International Prostatic Symptom Score (IPSS) [32] and the sexual dysfunction was evaluated using the International Index of Erectile Function (IIEF) [33] showed in Table 3.

As can be seen from the results, again in high vascular ligation, as well as in lymph dissection around the root of the IMA, often through the use of high-energy devices, impairment of urinary and sexual function in the first postoperative year is significantly more pronounced than in the LT group.

**Discussion**

LH or HT? Oncological considerations indicate that lymphatic dissection in a plan by isolated ligation of the sigmoid branches is close to tubular resection (in non-oncological diseases) and is an unacceptable approach. Only one study
gives an equivalent in oncological results to high vascular ligation and isolated ligation of sigmoid vessels [34], but it is of low quality and rejected by critics. At the opposite end is the TME with high vascular ligation.

HT vascular ligation attempts to achieve tension-free anastomosis and more harvested lymph nodes. However, LT is a preferred option, based on the absence of significant evidence for a difference in specific oncological survival and due to more accurate preservation of proximal intestinal segment microperfusion to prevent anastomotic insufficiency, also for its lower risk of damage to the hypogastric plexus [8,19,20,32,35]. The results of the present study did not find a significant difference in the incidence of anastomotic leak which is one of the most serious postoperative complications [13,36,37]. However, in case of intention to perform low or ultra-low anterior resection, the need to ensure the absence of tension loading of the anastomosis, we prefer to perform high tie and splenic flexure mobilization. SFM is necessary in most cases and it provides elongation of the proximal intestinal segment, but data from the literature indicate that there is no proven effect on anastomotic leakage incidence. It increases surgical duration and is in fact necessary in only 30% of the cases according to the publications [17,18,38]. However, in our study the duration of surgery was significantly longer in the group with high vascular ligation and SFM, regardless of the surgeon’s experience. In terms of the number of intraoperative complications, the data from our study show a significantly lower rate of complications in the group with low vascular ligation. An innovation in our study is the adoption and enforcement of the LT approach with additional dissection of the apical lymph node group, which improves N-staging while reducing anastomotic leak rate. In this group there is no significant difference in the anastomotic leakage rate, as well as in the oncological results, but there is a significant increase in the number of lymph

| Table 2 | Defecatory dysfunction in anterior resection of the rectum patients from the three groups in the first 12 months after surgery |
|----------------|----------------------------------------|----------------|-----------------|-----------------|----------------|-----------------|-----------------|
| Symptoms in first 12 months | Group A—HT | Group B—LT | Group C—LT-LND | p-value |
| Fecal and gas incontinence (Jorge–Wexner score > 5) | 28 (24%) | 9 (16%) | 8 (20%) | (A–B) p = 0.023 (A–C) p = 0.123 (B–C) p = 0.024 |
| Urgency | 19 (16%) | 8 (15%) | 7 (18%) | (A–B) p = 0.524 (A–C) p = 0.141 (B–C) p = 0.101 |
| Frequent bowel movements | 21 (18%) | 12 (23%) | 8 (20%) | (A–B) p = 0.025 (A–C) p = 0.012 (B–C) p = 0.069 |
| Clustering of stools | 12 (10%) | 12 (23%) | 5 (13%) | (A–B) p = 0.022 (A–C) p = 0.064 (B–C) p = 0.034 |
| Difficulty emptying | 41 (35%) | 9 (16%) | 12 (30%) | (A–B) p = 0.021 (A–C) p = 0.081 (B–C) p = 0.033 |
| Averages for significant difference | ≈(A–B) p = 0.03 | ≈(A–C) p = 0.07 | ≈(B–C) p = 0.04 |

| Table 3 | Urinary and sexual dysfunction in anterior resection of the rectum patients from the three groups in the first 12 months after surgery |
|----------------|----------------------------------------|----------------|-----------------|-----------------|-----------------|-----------------|
| Symptoms in first 12 months | Group A—HT | Group B—LT | Group C—LT-LND | p-value |
| IPSS score > 5–35 | 30 (26%) | 7 (13%) | 12 (31%) | (A–B) p = 0.011 (A–C) p = 0.039 (B–C) p = 0.023 |
| IIEF score < 20 | 66 (57%) | 24 (45%) | 23 (59%) | (A–B) p = 0.022 (A–C) p = 0.182 (B–C) p = 0.033 |
| Averages for significant difference | ≈(A–B) p = 0.02 | ≈(A–C) p = 0.06 | ≈(B–C) p = 0.024 |

Statistically significant p < 0.05 values are given in italics.
nodes obtained. However, our results show that in this group the operating time is longer, but still decreases with gaining experience and reaching a plateau of the learning curve. In these patients, as well as in the HT group, there is a more pronounced impairment of defecation and urinary/sexual function in the first year postoperatively.

Our study has certain limitations. First of all, there is no randomization in the stratification and prospective follow-up of the participants in the target groups. In addition, the accepted concept of protective intestinal stoma formation in low and ultralow anterior resection does not allow for clear identification of anastomotic leakage in the early postoperative period in all studied patients with the possibility of bias in interpretation of the results from all groups. Another innovation is the use of fluorescence assessment of the microperfusion of anastomotic segments to influence the anastomotic leakage rate, but the number of patients with this procedure is quite limited and it is insufficient for quality statistical processing.

**Conclusion**

At the present moment there is no precise data whether LT has an advantage in terms of prevention of autonomic nervous and urogenital dysfunction. New prospective randomized and highly evidential studies are needed in order to standardize the procedures in specific clinical situations.

**Declarations**

Disclosures The participants in the team of this study declare that they do not have any financial obligations or benefits from conducting and the consequences of this study. Drs. Manol Bonev Sokolov, Boril Petrov, Sviilen Maslyankov, Kostadin Angelov, Margarita Atanasova, Dochka Tzoneva and Petar Gribnev have no conflicts of interest or financial ties to disclose.

**References**

1. Loeweneck H, Feifel G (1993) Lanz Wachsmuth Praktische Anatomie Bauch. Springer, Berlin
2. Lange MM, Buunen M, van de Velde CJ, Lange JF (2008) Level of arterial ligation in rectal cancer surgery: low tie preferred over high tie. A review. Dis Colon Rectum 51(7):1139–1145. https://doi.org/10.1007/s10350-008-9328-y
3. Tepper JE, O’Connell MJ, Niedzwiecki D et al (2001) Impact of number of nodes retrieved on outcome in patients with rectal cancer. J Clin Oncol 19:157–163
4. Prandi M, Lionetto R, Bini A et al (2002) Prognostic evaluation of stage B colon cancer patients is improved by an adequate lymphadenectomy: results of a secondary analysis of a large scale adjuvant trial. Ann Surg 235:458–463
5. Kanemitsu Y, Hirai T, Komori K, Kato T (2006) Survival benefit of high ligation of the inferior mesenteric artery in sigmoid colon or rectal cancer surgery. Br J Surg 93:609–615
6. Yasuda K, Kawai K, Ishihara S, Murono K, Otani K, Nishikawa T, Tanaka T, Kiyomatsu T, Hata K, Nozawa H, Yamaguchi H, Aoki S, Mishima H, Maruyama T, Sako A, Watanabe T (2016) Level of arterial ligation in sigmoid colon and rectal cancer surgery. World J Surg Oncol. https://doi.org/10.1186/s12957-016-0819-3
7. Sugarbaker PH (1993) Metastatic inefficiency: the scientific basis for resection of liver metastases from colorectal cancer. J Surg Oncol Suppl 3:158–160
8. Sauer I, Bacon HE (1952) A new approach for excision of carcinoma of the lower portion of the rectum and anal canal. Surg Gynecol Obstet 95:229–242
9. Hida J, Yasutomi M, Maruyama T, Fujimoto K, Nakajima A, Uchida T, et al (1998) Indication for using high ligation of the inferior mesenteric artery in rectal cancer surgery. Examination of nodal metastases by the clearing method. Dis Colon Rectum 41(8):984–987
10. Bruch HP, Schwandner O, Schiedeck TH, Roblick UJ (1999) Actual standards and controversies on operative technique and lymph-node dissection in colorectal cancer. Langenbecks Arch Surg 384(2):167–175
11. Wexner SD (1998) Invited editorial. Dis Colon Rectum 41:987–989
12. You X, Liu Q, Wu J, Wang Y, Huang Ch, Cao G, Dai J, Chen D, Zhou Y (2020) High versus low ligation of inferior mesenteric artery during laparoscopic radical resection of rectal cancer. Medicine 99(12):e19437. https://doi.org/10.1097/MD.0000000000019437
13. Fujii C, Ishibe A, Ota M, Watanabe K, Watanabe J, Kunisaki C et al (2018) Randomized clinical trial of high versus low inferior mesenteric artery ligation during anterior resection for rectal cancer. BJIS Open 2(4):195–202. https://doi.org/10.1002/bjis.5.71
14. Boström P, Haapamäki MM, Matthiessen P, Ljung R, Rutegård J, Rutegård M (2015) High arterial ligation and risk of anastomotic leakage in anterior resection for rectal cancer in patients with increased cardiovascular risk. Colorectal Dis 17(11):1018–1027. https://doi.org/10.1111/codi.12971
15. Jafari MD, Lee KH, Halabi WJ, et al (2013) The use of indocyanine green fluorescence to assess anastomotic perfusion during robotic assisted laparoscopic rectal surgery. Surg Endosc 27:3003–3008
16. Jafari MD, Wexner SD, Martz JE, McLemore EC, Margolin DA, Sherwinter DA, et al. Perfusion assessment in laparoscopic left sided/anterior resection (PILLAR) II: A multi-institutional study. Ann Surg. A 2015 by Journal of the American College of Surgeons. Published by Elsevier Inc.open access article under the CC BY-NC-SA license,Vol. 220, No. 1, January 2015, pp 82–92 (http://creativecommons.org/licenses/by-nc-sa/3.0/); www.elemntalhealthcare.co.uk
17. Hoer J, Roegels A, Prescher A, Klosterhalfen B, Tons C, Schumpelick V (2000) Preserving autonomic nerves in rectal surgery. Results of surgical preparation on human cadavers with fixed pelvic sections. Chirurg. 71(10):1222–1229
18. Nano M, Dal Corso H, Ferronato M, Solej M, Hor- ning JP, Dei PM (2004) Ligation of the inferior mesenteric artery in the surgery of rectal cancer: anatomical considerations. Dig Surg 21(2):123–126. https://doi.org/10.1159/000077347
19. Zhou ZG, Hu M, Li Y, Lei WZ, Yu YY, Cheng Z et al (2004) Laparoscopic versus open total mesorectal excision with anal sphincter preservation for low rectal cancer. Surg Endosc 18(8):1211–1215. https://doi.org/10.1007/s00464-003-9170-1
20. Matsuda K, Hotta T, Takifuji K, Yokoyama S, Oki Y, Watanabe T et al (2015) Randomized clinical trial of defaecatory function after anterior resection for rectal cancer with high versus low ligation of...
21. Mari GM, Crippa J, Cocozza E, Berselli M, Livraghi L, Carzaniga P, Valenti F, Roscio F, Ferrari G, Mazzola M, Magistro C, Orig M, Forgione A, Zuliani W, Scandroglio I, Pugliese R, Costanzi ATM, Maggioni D (2019) Low ligation of inferior mesenteric artery in laparoscopic anterior resection for rectal cancer reduces genitourinary dysfunction: results from a randomized controlled trial (HIGHLOW Trial). Ann Surg 269(6):1018–1024. https://doi.org/10.1002/bsj.3587

22. Bonnet S, Berger A, Hentati N, Abid B, Chevallier JM, Wind PE et al (2012) High tie versus low tie vascular ligation of the inferior mesenteric artery in colorectal cancer surgery: impact on the gain in colon length and implications on the feasibility of anastomoses. Dis Colon Rectum 55(5):515–521. https://doi.org/10.1097/DCR.0b013e318246f1a2

23. Corder AP, Karanjia ND, Williams JD, Heald RJ (1992) Flush aortic tie versus selective preservation of the ascending left colic artery in low anterior resection for rectal carcinoma. Br J Surg 79(7):680–682. https://doi.org/10.1002/bjs.1800790730

24. Pezim ME, Nicholls RJ (1984) Survival after high or low ligation of the inferior mesenteric artery during curative surgery for rectal cancer. Ann Surg 200(6):729–733

25. Ke TW, Geniales CR, Chen WTL (2018) The role of splenic flexure mobilization in laparoscopic rectal surgery for rectal cancer. Int J Surg 31:27–32. https://doi.org/10.1016/j.ijsu.2016.05.042

26. Reddy SH, Gupta V, Yadav TD, Singh G, Sahni D (2016) Lengthening of left colon after rectal resection: what all is adequate? A prospective cohort study. Int J Surg 31:27–32. https://doi.org/10.1016/j.ijss.2016.05.042

27. Longo W, Reddy V, Audisio R (2014) Modern Management of Cancer of the Rectum. 2nd ed. Springer. https://www.springer.com/gp/book/9781447103318

28. Gouvas N, Gogos-Pappas G, Tsimogiannis K, Agalianos C, Tsimoyiannis E, Dervenis C, Xynos E (2014) Impact of splenic flexure mobilization on short-term outcomes after laparoscopic left colectomy for colorectal cancer. Surg Laparosc Endosc Percutan Tech 24(5):470–474. https://doi.org/10.1097/SLE.0b013e31829ce62a

29. Girard E, Trilling B, Rabattu PY, Sage PY, Tatou N, Robert Y et al (2019) Level of inferior mesenteric artery ligation in low rectal cancer surgery: high tie preferred over low tie. Tech Coloproctol 23(3):267–271. https://doi.org/10.1007/s10151-019-01931-0

30. Kennedy R, Jenkins I, Finan PJ (2008) Controversial topics in surgery: splenic flexure mobilisation for anterior resection performed for sigmoid and rectal cancer. Ann R Coll Surg Engl 90(8):638–642. https://doi.org/10.1308/003588408X358774

31. Hajibande S, Hajibande S, Maw A (2020) Meta-analysis and trial sequential analysis of randomized controlled trials comparing high and low ligation of the inferior mesenteric artery in rectal cancer surgery. Dis Colon Rectum 63(7):988–999. https://doi.org/10.1097/DCR.0000000000001693

32. Barry MJ, Fowler FJ, Jr, O’Leary MP, Bruskewitz RC, Holfgrewe HL, Mebus WK (1992) The American Urological Association symptom index for benign prostatic hyperplasia. The measurement committee of the American Urological Association. J Urol 148:1549–1557

33. Rosen RC, Riley A, Wagner G, Osterloh IH, Kirkpatrick J, Mishra A (1997) The international index of erectile function (IIEF): a multidimensional scale for assessment of erectile dysfunction. Urology 49:822–830

34. Srikurn.ppooon S, Angkurawaron C, Pinyoppanpratarn R, Vitoopinyopar S, Muyphuag B, Chantawibul S, Ratanachu-ek T. (2017). Low ligation inferior mesenteric artery versus selective sigmoidal artery ligation in sigmoid colon cancer: a comparative study. Int Surg J 4:3201. https://doi.org/10.18203/2349-2902.isj20174489

35. Goldstein NS, Sanford W, Coffey M, Layfield LJ (1996) Lymph node recovery from colorectal resection specimens removed for adenocarcinoma. Trends over time and a recommendation for a minimum number of lymph nodes to be recovered. Am J Clin Pathol. 106:209–216

36. Rutegård M, Hassmén N, Hemmingsson O, Haapamäki MM, Matthiessen P, Rutegård J. (2019). Anterior resection for rectal cancer and visceral blood flow: an explorative study. Scand J Surg 105(2):78–83. https://doi.org/10.1177/1457496915593692

37. Hinoi T, Okajima M, Shimomura M, Ogita H, Ohdan H, Konishi F et al (2013) Effect of left colonic artery preservation on anastomotic leakage in laparoscopic anterior resection for middle and low rectal cancer. World J Surg 37(12):2935–2943. https://doi.org/10.1007/s00268-013-2194-3

38. Tsujinaka S, Kawamura YJ, Tan KY, Mizokami K, Sasaki J, Maeda T et al (2012) Proximal bowel necrosis after high ligation of the inferior mesenteric artery in colorectal surgery. Scand J Surg 101(1):21–25. https://doi.org/10.1177/145749691210100105

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