DOI: 10.4274/tjcd.galenos.2019.2020-0-0-0
Turk J Colorectal Dis 2020;30:9-16

REVIEW

Cytoreductive Surgery for Advanced Colon Cancer

İleri Kolon Kanseri için Sitoredüktif Cerrahi

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ABSTRACT

Peritoneal metastases from appendiceal and colorectal cancer continue to be a major threat to a favorable outcome with treatment.
Reliable treatment strategies for the management of appendiceal and colorectal cancer start with the complete surgical removal of the disease. The surgical technology to accomplish this goal in patients with peritoneal metastases was reviewed.
Electrosurgical dissection techniques and wide open exposure of the abdomen and pelvis were described. Five peritoneal stripping (peritonectomy) procedures were presented and integrated with visceral resections that may be required. Techniques to remove cancer nodules from small bowel and small bowel mesentery were itemized.
Technology for complete resection of peritoneal metastases from patients with appendiceal and colorectal cancer was described and it can improve treatment outcomes for these patients.
Keywords: Peritoneal metastases, peritonectomy, cytoreductive surgery, electrosurgery, intraperitoneal chemotherapy

ÖZ

Apendiks ve kolorektal kanserden peritoneal metastazlar, tedavi ile olumlu bir sonuç alınması için büyük bir tehdit olmaya devam etmektedir. Apendiks ve kolorektal kanserin yönetimi için güvenilir tedavi stratejileri, hastalığın tamamen cerrahi olarak çıkarılması ile başlar. Bu çalışmada peritonal metastazı olan hastalarda bu amaca ulaşmak için kullanılan cerrahi teknoloji gözden geçirilmiştir. Elektrocerrahi diseksiyon teknikleri ile birlikte karın ve pelvisin detaylı ve açık bir şekilde ekspoze edilmesi tanımlandı. Beş periton sıyırma (peritonektomi) prosedürü sunuldu ve gerekli olabilecek viseral rezeksiyonlarla entegre edildi. İnce barsaktan ve ince barsak mezenterinden kanser nodüllerini çıkarma teknikleri verildi. Apendiks ve kolorektal kanseri olan hastalardan periton metastazlarının tam rezeksiyonu için teknoloji tanımlandı.
Anahtar Kelimeler: Periton metastazı, peritonektomi, sitoredüktif cerrahi, elektrocerrahi, intraperitoneal kemoterapi

Introduction

As cancer surgery expanded in the midst of a technological revolution in patient care, this discipline accepted responsibilities not only for the resection of primary tumor but also for the surgical management of metastatic disease. Aggressive management strategies to bring about long-term survival to patients with peritoneal surface malignancy have been pioneered by our group.[1,2] Successful treatment of abdominal and pelvic malignancies that disseminate to peritoneal surfaces has resulted from extensive experience with appendiceal cancer. Appendiceal cancer became the paradigm for successful treatment of peritoneal metastases (PM).[3,4] This review presents the concepts for and the technique of cytoreduction that optimally prepares the patient for chemotherapy used in the operating room with hyperthermia with acceptable morbidity and mortality.

Principles of Management

The successful treatment of peritoneal surface malignancy requires a comprehensive management plan that utilizes cytoreductive surgery (CRS) and perioperative chemotherapy. In addition, proper patient selection is mandatory. Complete resection of all visible malignancy is essential for the treatment of peritoneal surface malignancy to result in long-term survival. Up to five peritonectomy

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Received/Geliş Tarihi: 24.12.2019 **Accepted/Kabul Tarihi:** 24.12.2019

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Turkish Journal of Colorectal Disease published by Galenos Publishing House.

procedures may be required.[5] The visceral resections and parietal peritonectomy procedures that one must utilize to adequately resect all visible evidence of disease are shown in Table 1. Their utilization depends on the distribution and extent of invasion of the malignancy disseminated within the peritoneal space. Normal peritoneum is not excised, only that which is implanted by cancer.

Peritonectomy Procedures and Visceral Resections

Rationale for Peritonectomy Procedures and Visceral Resections

Peritonectomy procedures are necessary if one is to successfully treat peritoneal surface malignancies with curative intent. Peritonectomy procedures are used in the areas of visible cancer progression in an attempt to leave the patient with only microscopic residual disease. Isolated tumor nodules on parietal peritoneum may be removed using electroevaporation. Involvement of the visceral peritoneum frequently requires the resection of a portion of the stomach, small intestine, or colorectum. Layering of cancer on a peritoneal surface or a portion of the bowel requires peritonectomy or bowel resection for complete removal.

Locations of Peritoneal Surface Malignancy

Peritoneal metastases, especially mucinous carcinomatosis, tend to involve the visceral peritoneum in greatest volume at three anatomic sites.[6] These are sites where the bowel is anchored to the retroperitoneum and peristalsis causes less motion of the visceral peritoneal surface. The rectosigmoid colon, as it emerges from the pelvis, is a non-mobile portion of the bowel. Also, it is located in a dependent site and therefore is frequently layered by peritoneal metastases. Usually, a complete pelvic peritonectomy requires stripping of the pelvic sidewalls, the peritoneum overlying the bladder, the cul-de-sac, and resection of the rectosigmoid colon. The ileocecal valve is another area where there is limited mobility. Resection of the terminal ileum and a small portion of the right colon is often necessary. A final site often requiring resection is the antrum of the stomach which is fixed to the retroperitoneum at the pylorus. Tumor coming into the foramen of Winslow accumulates in the subpyloric space and may cause intestinal obstruction as a result of gastric outlet obstruction.[7] Large volumes of tumor in the lesser omentum combined with disease in the subpyloric space may cause a confluence of disease that requires a total gastrectomy for complete cytoreduction.

Electroevaporative Surgery

In order to adequately perform peritonectomy, the surgeon must use electrosurgery.[8] The electrosurgical handpiece uses a ball tip that allows the tissue surfaces beneath the peritonectomy to be contoured (Valleylab, Boulder, CO). The smooth surface is then able to be resurfaced by peritoneum (Figure 1). Peritonectomies and visceral resections using traditional scissor and knife dissection will unnecessarily disseminate a large number of tumor cells within the abdomen. High voltage electrosurgery leaves a margin of heat necrosis that is devoid of viable malignant cells. Not only does electroevaporation of tumor and normal tissue at the margins of resection minimize the likelihood of persistent disease, but also it minimizes blood loss. In the absence of electrosurgery, profuse bleeding from stripped peritoneal surfaces may occur.

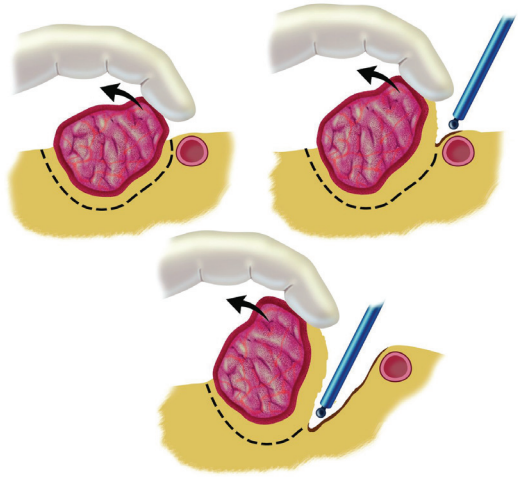


Figure 1. Ball-tipped electrosurgery is used to dissect and simultaneously provide small vessel hemostasis. Frequent room temperature saline irrigation is needed to prevent heat damage to tubular structures. A margin of heat necrosis from electrosurgical dissection at high voltage helps to prevent local recurrence. Smoke evacuation is required to prevent environmental contamination (From reference 5 with permission)

Table 1. Peritonectomy procedures and resections that are combined to complete a cytoreduction procedure

Peritonectomy	Resections
Anterior parietal peritonectomy	Old abdominal incisions, umbilicus and epigastric fat pad
Left upper quadrant peritonectomy	Greater omentectomy and spleen
Right upper quadrant peritonectomy	Tumor on Glisson's capsule of the liver
Pelvic peritonectomy	Uterus, ovaries and rectosigmoid colon
Omental bursectomy	Gallbladder and lesser omentum

Abdominal Exposure

The abdominal cavity is opened through a midline incision from the xiphoid to the pubis. The old abdominal incision is widely excised including the umbilicus. The skin edges are secured by heavy sutures to the self-retaining retractor. Traction on the edges of the abdominal incision elevates the structures of the abdominal wall to facilitate their accurate dissection (Figure 2). Strong elevation of abdominal wall helps to avoid damage to bowel loops that are adherent to the anterior abdominal wall.[9,10] Generous abdominal exposure is achieved through the use of a Thompson Self-Retaining Retractor (Thompson Surgical Instruments, Inc., Traverse City, MI).

Total Anterior Parietal Peritonectomy

As the peritoneum is dissected away from the posterior rectus sheath, a single entry into the peritoneal cavity in the upper portion of the incision (peritoneal window) allows the surgeon to assess the requirement for a complete parietal peritonectomy (Figure 3). If cancer nodules are palpated on the parietal peritoneum, a complete dissection may be indicated to achieve a complete cytoreduction. If the parietal peritoneum is not involved by PM, except for the small defect in the peritoneum required for this peritoneal exploration, the remainder of the peritoneum is maintained intact.

The self-retaining retraction system is steadily advanced along the anterior abdominal wall. This optimizes the broad traction at the point of dissection of the peritoneum from its underlying tissues. The dissecting tool is the ball tip, and smoke evacuation is used continuously.[11] It is most adherent directly overlying the transversus muscle. In some instances, dissection from inferior to superior aspects of the abdominal wall facilitates clearing in this area. The dissection blends in with the right and left subphrenic peritonectomy superiorly and with the complete pelvic peritonectomy inferiorly. As the dissection proceeds beyond the peritoneum overlying the paracolic sulcus (line of Toldt), the dissection becomes more rapid with the loose connections of the peritoneum at this anatomic site.

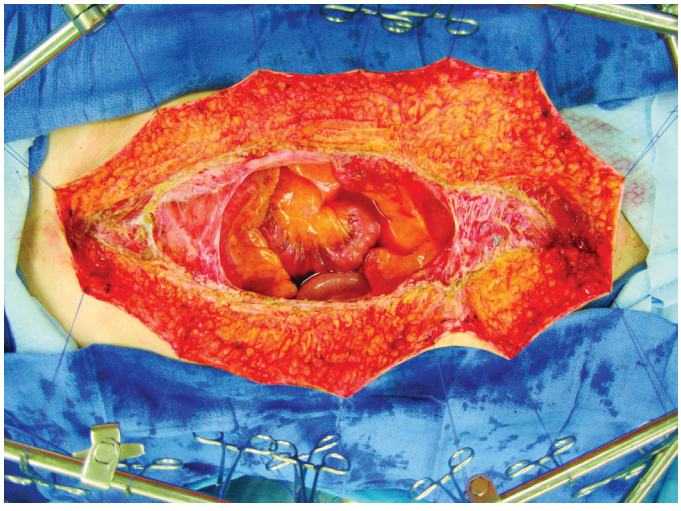


Figure 2. Elevation of the edges of the abdominal incision. Skin traction on a self-retaining retractor facilitates dissection of abdominal wall structures and minimizes the likelihood of damage to bowel loops adherent to the abdominal wall (From reference 5 with permission)

Left Subphrenic Peritonectomy

The peritonectomy procedures are greatly facilitated by the self-retaining retractor that provides continuous exposure of all quadrants of the abdomen including the pelvis. The epigastric fat and peritoneum at the edge of the abdominal incision are stripped off the posterior rectus sheath. Strong traction is exerted on the tumor specimen throughout the left upper quadrant in order to separate tumor from the diaphragmatic muscle, the left adrenal gland, and the superior half of the perirenal fat. The splenic flexure of the colon is severed from the left abdominal gutter and moved medially by dividing the peritoneum along Toldt's line. Dissection beneath the hemidiaphragm muscle must be performed with ball-tipped electrosurgery, not by blunt dissection (Figure 4). Numerous blood vessels between the diaphragm muscle and its peritoneal surface must be visualized and individually electrocoagulated before their transection or unnecessary bleeding will occur as the severed blood vessels retract into the muscle of the diaphragm. The plane of dissection is defined using ball-tipped electrosurgery on pure cut, but all blood vessels are electrocoagulated before their division.

Greater Omentectomy and Possible Splenectomy

To free the mid-abdomen of a large volume of tumor, the greater omentectomy-splenectomy is performed. The

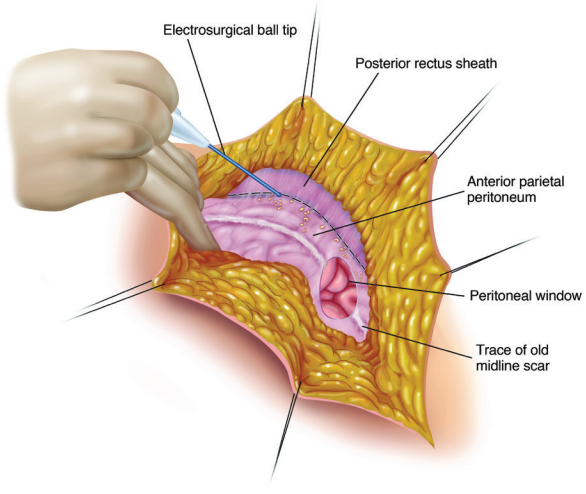


Figure 3. Peritoneal window is necessary to assess the need for total anterior parietal peritonectomy (From reference 5 with permission)

greater omentum is elevated and then separated from the transverse colon using electrosurgery. This dissection continues beneath the peritoneum that covers the transverse mesocolon in order to expose the lower border of the pancreas. The branches of the gastroepiploic arcade to the greater curvature of the stomach are ligated in continuity and then divided.

Because the left upper quadrant peritonectomy has been completed, the structures deep beneath the left hemidiaphragm can be elevated. Therefore, under direct vision, the short gastric vessels are transected. With traction on the spleen, the peritoneum superior to the pancreas may be stripped from the gland bluntly or by using electrosurgery. If the peritoneum covering the pancreas is free of cancer implants, it remains intact. The splenic artery and vein at the tail of the pancreas are ligated in continuity and proximally suture ligated. Great care is taken not to traumatize the body or tail of the pancreas.

Right Subphrenic Peritonectomy

Peritoneum is stripped from beneath the right posterior rectus sheath to begin the peritonectomy in the right upper quadrant of the abdomen. Strong traction on the specimen is used to elevate the hemidiaphragm into the operative field. Again, ball-tipped electrosurgery on pure cut is used to dissect at the interface of tumor and normal tissue. Coagulation current is used to divide the blood vessels between the diaphragm and peritoneum as they are encountered and before they bleed.

Stripping of Tumor from Glisson's Capsule

The stripping of tumor from the right hemidiaphragm continues until the bare area of the liver is encountered. At that point, tumor on the superior surface of the liver is electroevaporated until the liver surface is cleared (Figure 5). With ball-tipped electroevaporative dissection, a thick layer of tumor may be bloodlessly lifted off the liver surface by moving beneath Glisson's capsule (high voltage pure cut electrosurgical dissection). Isolated patches of tumor on the liver surface are electroevaporated with the distal 2 cm of the ball tip bent and stripped of insulation ("hockey-stick" configuration). Ball-tipped electrosurgery is also used to extirpate tumor from attachments of the falciform ligament and round ligament.

Tumor from beneath the right hemidiaphragm, from the right subhepatic space, and from the surface of the liver forms an envelope as it is removed en bloc. The dissection is greatly facilitated if the tumor specimen is maintained intact. The dissection continues laterally on the right to encounter the perirenal fat covering the right kidney. Also, the right adrenal gland is visualized and carefully avoided as tumor is stripped from the right subhepatic space. As the peritoneal reflection at the posterior aspect of the liver is divided, care is taken not to traumatize the vena cava or to disrupt the caudate lobe veins that pass between the vena cava and segment 1 of the liver.

Lesser Omentectomy and Cholecystectomy with Stripping of the Hepatoduodenal Ligament

The gallbladder is removed in a routine fashion from its fundus toward the cystic artery and cystic duct. These structures are ligated and divided. The hepatoduodenal ligament is characteristically heavily layered with tumor. After dividing the peritoneal reflection onto the liver, the cancerous tissue that coats the porta hepatis is bluntly stripped using Russian forceps from the base of the

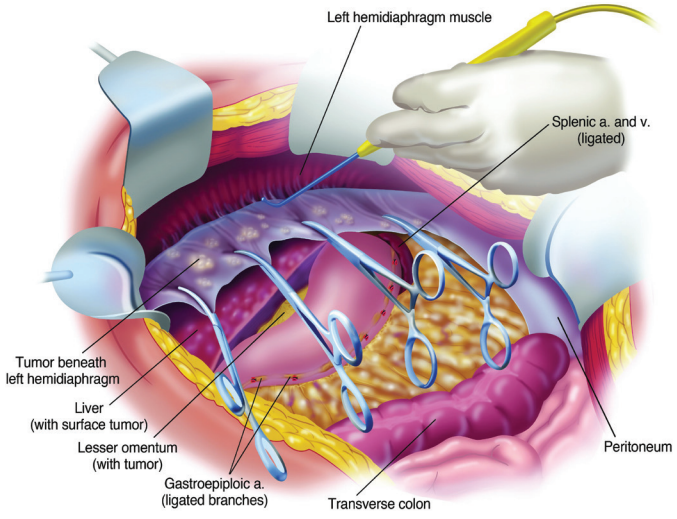


Figure 4. Peritoneal stripping of the undersurface of the left diaphragm (From reference 5 with permission)

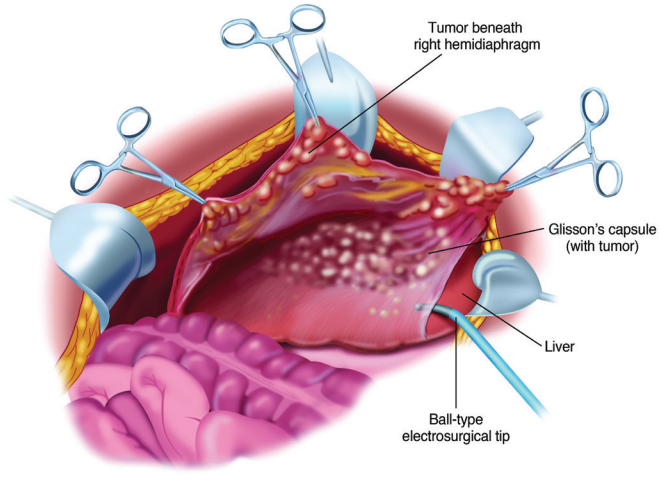


Figure 5. Electroevaporation of tumor from the liver surface with resection of Glisson's capsule (From reference 5 with permission)

gallbladder bed toward the duodenum. The right gastric artery going to the lesser omental arcade is preserved (Figure 6). To continue resection of the lesser omentum, the surgeon separates the gastrohepatic ligament from the fissure that divides liver segments 2 and 3 from segment 1. Ball-tipped electrosurgery is used to electroevaporate tumor from the surface of the caudate process. Care is taken not to traumatize the anterior surface of the caudate process, for this can result in excessive and needless blood loss. The segmental blood supply to the caudate lobe is located on the anterior surface of this segment of the liver, and hemorrhage may occur with only superficial trauma. Also, care must be taken to avoid an accessory left hepatic artery that may arise from the left gastric artery and cross through the hepatogastric fissure. If the artery is embedded in tumor or its preservation occludes clear exposure of the omental bursa, the artery is ligated as it enters the liver parenchyma. It is resected as part of the hepatogastric ligament.

Circumferential Resection of the Hepatogastric Ligament and Lesser Omental Fat by Digital Dissection

The triangular ligament of the left lobe of the liver was resected in performing the left subphrenic peritonectomy. This completed, the left lateral segment of the liver is retracted left to right to expose the hepatogastric ligament in its entirety. A circumferential electrosurgical release of this ligament (lesser omentum) from the fissure between liver segments 2 and 3, and the left caudate lobe, and from the arcade of right gastric artery to left gastric artery along the lesser curvature of the stomach is required. After electrosurgically dividing the peritoneum on the lesser curvature of the stomach, digital dissection with extreme pressure from the surgeon's thumb and index finger separates lesser omental fat and tumor from the vascular arcade. As much of the anterior vagus nerve is spared as is possible. The tumor and fatty tissue surrounding the right and left gastric arteries are split away from the vascular arcade. In this manner, the specimen is centralized over the major branches of the left gastric artery. With strong traction on the specimen, the lesser omentum is released from the left gastric artery and vein.

Stripping of the Floor of the Omental Bursa

A Dever retractor or the assistant's fingertips beneath the left caudate lobe are positioned to expose the entire floor of the omental bursa (Figure 7). Further electroevaporation of tumor from the caudate process of the left caudate lobe of the liver may be necessary to achieve this exposure. Ball-tip electrosurgery is used to cautiously divide the peritoneal reflection of the liver onto the left side of the subhepatic vena cava. After the peritoneum is divided, Russian forceps assist in a blunt stripping of the peritoneum from the superior recess of the omental bursa, from the crus of the right hemidiaphragm, and from beneath the portal vein. Electroevaporation of tumor from the shelf of the liver parenchyma beneath the portal vein that connects right and left aspects of the caudate lobe may be required. Care is taken while stripping the floor of the omental bursa to stay superficial to the right phrenic artery.

In some patients, a large volume of tumor on the posterior aspect of the hepatoduodenal ligament may be difficult to visualize. A 1/2 inch Penrose drain placed around the portal triad may allow improved visualization beneath these structures. Using Russian forceps tearing away the peritoneum beneath the porta hepatis may be necessary under direct visualization.

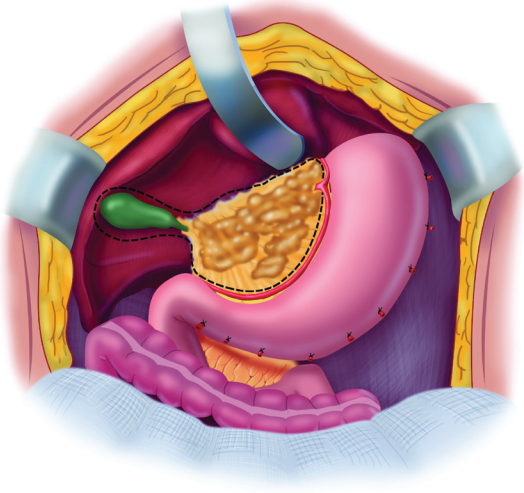


Figure 6. Lesser omentectomy and cholecystectomy with stripping of the anterior and posterior (if necessary) aspect of the hepatoduodenal ligament (From reference 5 with permission)

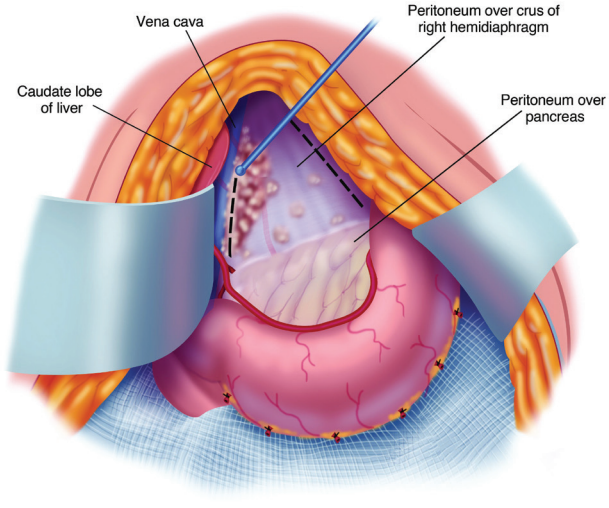


Figure 7. Stripping of the omental bursa after dividing the peritoneal reflection between the left caudate lobe and superior vena cava (From reference 5 with permission)

Complete Pelvic Peritonectomy

The tumor-bearing peritoneum is stripped from the posterior surface of the lower abdominal incision, exposing the rectus muscle. After dissecting generously the peritoneum on the right and left sides of the bladder, the urachus is localized and placed on strong traction using a Babcock clamp. The peritoneum with the underlying fatty tissues is stripped away from the surface of the bladder. Broad traction on the entire anterior parietal peritoneal surface and frequent saline irrigation clears the point for tissue transection that is precisely located between the bladder musculature and its adherent fatty tissue with the peritoneum. The inferior limit of dissection is the cervix in the female or the seminal vesicles in the male.

The peritoneal incision around the pelvis is connected to the peritoneal incisions of the right and left paracolic sulci (Figure 8). In the female, the round ligaments are divided as they enter the internal inguinal ring. The right and left ureters are identified and preserved. In women, the right and left ovarian veins are ligated at the level of the lower pole of the kidney and divided. A linear stapler is used to divide the sigmoid colon just above the limits of the pelvic tumor. The vascular supply of the distal portion of the bowel is traced back to its origin on the aorta. The inferior mesenteric artery is ligated, suture ligated and divided. This allows one to pack all the viscera, including the proximal sigmoid colon, in the upper abdomen.

Resection of Rectosigmoid Colon and Cul-de-Sac of Douglas

Electrosurgery is used to dissect at the limits of the mesorectum. The surgeon works in a centripetal fashion.

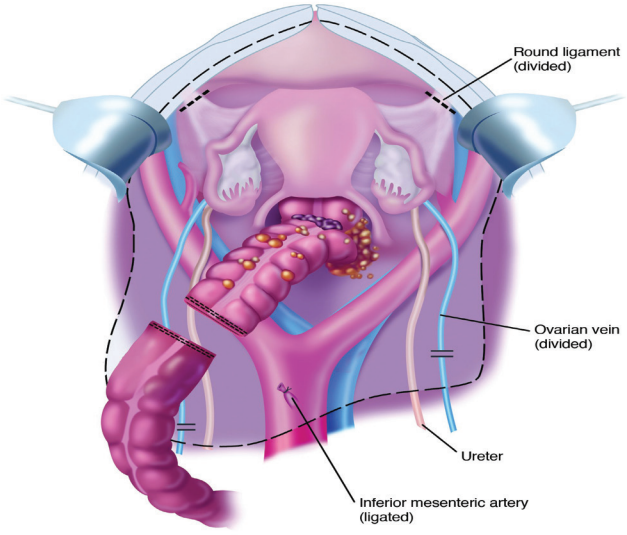


Figure 8. The complete pelvic peritonectomy includes the uterus and ovaries, rectosigmoid colon and pelvic peritoneum (From reference 5 with permission)

Extraperitoneal ligation of the uterine arteries is performed just above the ureter and close to the base of the bladder. The bladder is dissected away from the cervix and the vagina is entered. The vaginal cuff anterior and posterior to the cervix is transected using electrosurgery, and the rectovaginal septum is exposed. The perirectal fat is divided beneath the peritoneal reflection so that all tumor that occupies the cul-de-sac is removed intact with the specimen. The rectal musculature is skeletonized using electrosurgery so that a stapler can be used to close off the rectal stump.

Vaginal Closure and Low Colorectal Anastomosis

One of the few suture repairs performed prior to the intraoperative chemotherapy is the closure of the vaginal cuff. If one fails to close the vaginal cuff, chemotherapy solution will leak from the vagina. The circular stapled colorectal anastomosis occurs after the intraoperative chemotherapy has been completed. A circular stapling device is passed into the rectum, and the trochar penetrates the staple line. A purse-string applier is used to secure the staple anvil in the distal descending colon. The body of the circular stapler and anvil are mated, and the stapler is activated to complete the low colorectal anastomosis.

Optimization of Cytoreduction of Small Bowel and Its Mesentery

The peritonectomy procedures using high-voltage electrosurgery have been applied to the cytoreduction of parietal peritoneal surface malignancy. However, the electrosurgical techniques used in the peritonectomy procedures are not appropriate for the treatment of tumor nodules involving the small bowel. Only a very limited use of electrosurgery on the small bowel itself is possible in order to avoid postoperative fistula. In contrast, small bowel mesentery is an anatomic site for safe use of electroevaporation of cancer nodules.

Five Types of Small Bowel Involvement by Cancer

CRS with perioperative chemotherapy has been most commonly used for the management of mucinous appendiceal neoplasms but they have been successfully applied to other tumors, especially colon cancer and diffuse malignant peritoneal mesothelioma. The histological features and the depth of invasion of these different tumors into the bowel wall are not uniform. Based on the extent of the invasion, the size of the tumor nodule and its anatomic location on the bowel wall, small bowel involvement is classified into five types[12]:

Type 1. Non-invasive nodules.

Type 2. Small invasive nodules on the anti-mesenteric portion of the small bowel.

Type 3. Moderate size invasive nodules on the anti-mesenteric portion of the small bowel.

Type 4. All sizes of invasive nodules at the junction of the small bowel and its mesentery.

Type 5. Large invasive nodules.

Techniques Used in Cytoreduction of the Small Bowel

Type 1. Non-invasive nodules: This type of small bowel involvement involves minute nodules of aggressive histology that have not invaded past the peritoneum because of their small size. It would also include large non-invasive nodules of diffuse peritoneal adenomucinosis or nuclear grade I peritoneal mesothelioma.[13,14] The curved Mayo scissors are used to trim these non-invasive nodules from the surface of the small bowel; this results in a localized removal of peritoneum. Larger nodules are frequently scissor-dissected in a piecemeal fashion to avoid damage to the deeper layers of the bowel wall. Considerable skill acquired over time may be needed to avoid damage to the muscularis propria of the bowel (Figure 9). There is usually no need for seromuscular repair.

Type 2. Small invasive nodules on the anti-mesenteric portion of the small bowel: These invasive nodules do not separate from the muscular layer of the small bowel and a partial thickness resection is required. The seromuscular layer is resected leaving mucosa and submucosa intact. This resection is usually performed with a curved Mayo scissor but occasionally it may be performed by pure cut electrosurgery with frequent irrigation to cool the resection site. Scissor or knife dissection is preferred. The seromuscular layer is repaired by suture plication after the intraoperative chemotherapy is completed (Figure 10).

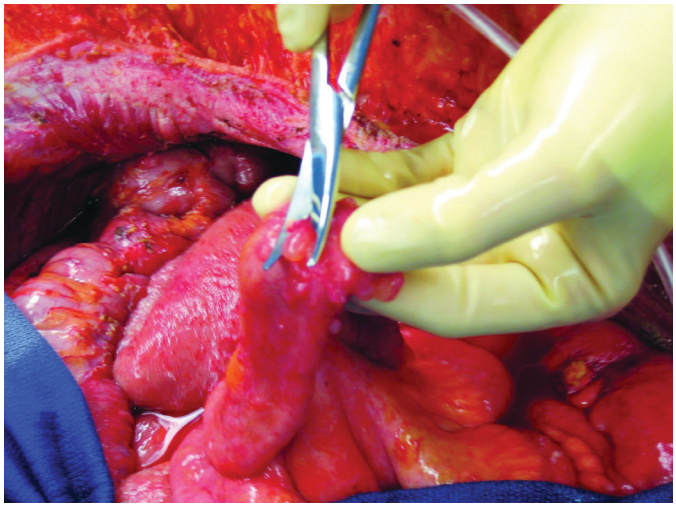


Figure 9. Type 1 - non-invasive tumor nodules are usually resectable using a curved Mayo scissor (From reference 5 with permission)

Type 3. Moderate size invasive nodules on the anti-mesenteric portion of the small bowel: In contrast to small invasive nodules in this location, larger nodules require a full thickness elliptical resection of the anti-mesenteric portion of the bowel wall. The closure is performed in two layers and at two different times. The first layer is a full thickness closure using absorbable suture. One suture starts at each corner of the defect and the sutures are then tied at the mid-portion of the resection. Following the POC, the defect is closed with a second layer of non-absorbable plication sutures (Figure 11).

Type 4. Small invasive nodules at the junction of the small bowel and its mesentery: These nodules can sometimes be removed by a localized removal with electrosurgery if sufficiently small and if the vascular supply to the segment of bowel is not compromised. A two-layer repair follows this localized resection. More often, these nodules are removed, and the incidence of fistula is reduced by a segmental small bowel resection with end-to-end hand-sewn anastomosis (Figure 12).

Type 5. Large invasive nodules: These lesions require a segmental small bowel resection with generous proximal and distal margins on the bowel wall and on the mesentery. The segment of small bowel and a portion of its mesentery are resected. The bowel is divided and closed using a linear cutter/stapler. The HIPEC is completed prior to a two-layer hand-sewn anastomosis (Figure 12).

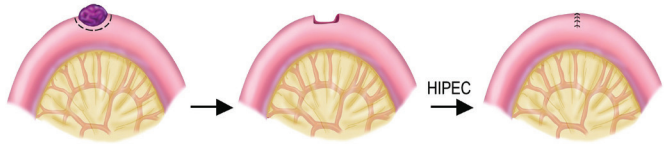


Figure 10. Type 2 - small invasive tumor nodules on the anti-mesenteric portion of the small bowel are resected along with the seromuscular layer. Hyperthermic intraperitoneal chemotherapy is administered prior to suture plication of the defect (From reference 5 with permission)

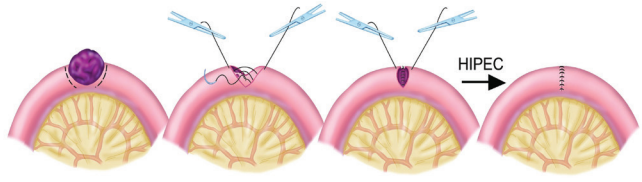


Figure 11. Type 3 - moderate sized invasive nodules on the anti-mesenteric portion of the small bowel are resected with a full thickness ellipse. Stay sutures elevate the portion of bowel to be resected. A full thickness closure with absorbable, running suture allows hyperthermic intraperitoneal chemotherapy to be given. After the intraperitoneal chemotherapy, a second layer of non-absorbable interrupted sutures is used to plicate the seromuscular layer (From reference 5 with permission)

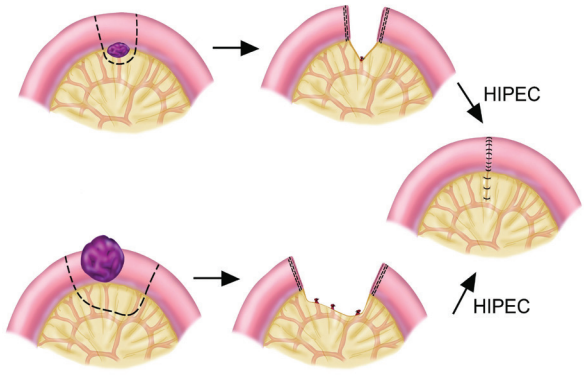


Figure 12. Small invasive nodules at the junction of the small bowel and mesentery (Type 4) or large invasive nodules (Type 5) are resected with generous margins using a linear stapler. After hyperthermic intraperitoneal chemotherapy is complete, a two-layer anastomosis is performed (From reference 5 with permission)

Peer-review: Internally peer reviewed.

Financial Disclosure: The authors declared that this study received no financial support.

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