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Optimal Complete Rectum Mobilization Focused on the Anatomy of the Pelvic Fascia and Autonomic Nerves: 30 Years of Experience at Severance Hospital

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The primary goal of surgery for rectal cancer is to achieve an oncologically safe resection, i.e., a radical resection with a sufficient safe margin. Total mesorectal excision has been introduced for radical surgery of rectal cancer and has yielded greatly improved oncologic outcomes in terms of local recurrence and cancer-specific survival. Along with oncologic outcomes, functional outcomes, such as voiding and sexual function, have also been emphasized in patients undergoing rectal cancer surgery to improve quality of life. Intraoperative nerve damage or combined excision is the primary reason for sexual and urinary dysfunction. In the past, these forms of damage could be attributed to the lack of anatomical knowledge and poor visualization of the pelvic autonomic nerve. With the adoption of minimally invasive surgery, visualization of nerve structure and meticulous dissection for the mesorectum are now possible. As the leading hospital employing this technique, we have adopted minimally invasive platforms (laparoscopy, robot-assisted surgery) in the field of rectal cancer surgery and standardized this technique globally. Here, we review a standardized technique for rectal cancer surgery based on our experience at Severance Hospital, suggest some practical technical tips, and discuss a couple of debatable issues in this field.

Key Words: Total mesorectal excision, anatomy, rainbow technique, rectal cancer

INTRODUCTION

The rates of local recurrence after rectal cancer surgery are usually high due to the challenges encountered during resection, including the narrow pelvis and the close proximity of the rectum to the neighboring organs, especially in low-lying rectal cancer.[1,2] Over the past decades, local recurrence, as well as survival, after proctectomy have improved with the adoption of multimodality approaches for management and with improvements in operative techniques and the development of minimally invasive procedures, including laparoscopic and robotic total mesorectal excision (TME).[3]

The TME technique was first introduced by Heald[4] in 1979. It includes sharp pelvic dissection of the mesorectum, which is considered the container of the draining lymph nodes, as well as the blood vessels surrounding the rectal cancer. The dissection should be performed between the visceral and parietal fasciae of the pelvis in a completely avascular plane that is called the holy plane. After adoption of the TME technique, the local recurrence rates decreased to 6–12% and the 5-year survival rate increased up to 53–87%.[5-8]

As the surgical technique has been developed from open surgery to minimally invasive surgery (MIS), there has been some

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controversy regarding oncological outcomes according to the surgical technique. Recent multicenter randomized clinical trials evaluated the oncological outcomes of laparoscopic rectal cancer surgery. The MRC-CLASSIC, COLOR II, and COREAN trials found no differences in local recurrence or disease-free survival rates between laparoscopic and open surgery.[9-11] However, the non-inferiority of laparoscopic surgery, with respect to open surgery for rectal cancer, was not established on statistical analysis in the ACOSOG Z6051 and ALaCaRT trials.[12,13] Furthermore, the superiority of robotic surgery over laparoscopic surgery was not proven in the ROLARR trial.[14] As shown in previous studies, advanced surgical techniques could not ensure better oncological outcomes. However, the selection of appropriate surgical technique, including laparoscopic or robotic surgery, can be helpful for patients in many ways.

With the improvement in survival outcomes after adopting TME, functional outcomes, such as sexual and urinary dysfunction, have also been highlighted.[15-18] In rectal cancer surgery, surgeons should have complete knowledge about the anatomy of the autonomic nerve, because functional outcomes are related to nerve damage during surgery. In open surgery, autonomic nerves and nerve plexuses are difficult to recognize, making it very difficult to avoid nerve injury. However, the nerve structure can be identified in MIS. The reported rates of urinary dysfunction and sexual dysfunction after rectal cancer surgery are 20–50% and 30–70%, respectively.[19-23] The development of MIS approaches for deep pelvic dissection and updated anatomical knowledge based on better technology for rectal cancer can improve our understanding of the anatomy of the pelvic fascia and nerve structure related to the surgical plane. Furthermore, these advancements can improve functional outcomes in patients who undergo surgery for rectal cancer.

In this review, we have attempted to standardize the technical steps for rectal mobilization to preserve the pelvic nerves and maintain the neighboring organs while ensuring adequate resectability from the point of view of an expert surgeon in colorectal cancer. We focused on the anatomy of the rectum, including the pelvic autonomic nerves, and techniques to preserve nerve structures while maintaining the mesorectal fascia (MRF). We also tried to delineate and describe the anatomy of Denonvilliers' fascia (DVF) and lateral attachment in more detail on the basis of a literature review: although DVF has been frequently studied, there is no consensus on its embryological origin and topological anatomy.

BASIC ANATOMY

Fascia

A proper understanding of the anatomy of the rectum, especially the fascia and autonomic nerve, is necessary to perform autonomic-nerve–preserving TME. Fig. 1 shows the relationships between the fascia around the rectum.[24] The fatty tissue encircling the rectum is called mesorectum. This structure should be resected together without damage in a TME for rectal cancer. It contains the possible metastatic lymph nodes and blood vessels and is enveloped with clear distinct collagenous fiber, the so-called "MRF" (i.e., the fascia propria of the rectum). The MRF corresponds to the visceral fascia.[25] Basically, dissection should be performed along the MRF to prevent nerve injury. The presacral fascia refers to the membrane that adheres to the periosteum over the sacrum.[26] At the S4 level, relatively dense connective tissue links the presacral fascia and the MRF. This is called the recto-sacral fascia (Waldeyer's fascia).[27] DVF is present between the seminal vesicle and the rectum in men and appears as a rectovaginal septum in women.[28]

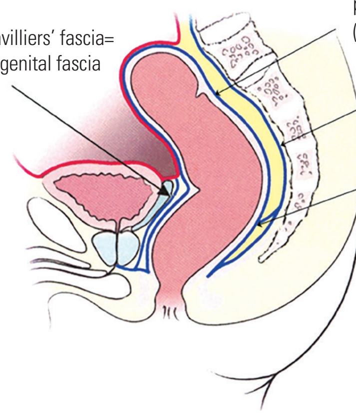

Fig. 1. The relationship between fascia around the rectum. The rectal proper fascia, the fascia covering the mesorectum, is also called visceral endopelvic fascia; the presacral fascia, the fascia covering the sacrum, is also called the parietal endopelvic fascia; Denonvilliers' fascia, a dense membrane between the rectum and the seminal vesicles, is also called the rectogenital fascia; Waldeyer's fascia is a dense connective tissue layer between the posterior part of the rectal proper fascia and the presacral fascia at the S3 and S4 levels. Adapted from Lee et al. Ann Coloproctol 2018;34(2):59-71.[24]

Autonomic nerve

Autonomic innervation of the pelvic viscera is formed by sympathetic fibers from the inferior hypogastric plexus and parasympathetic fibers from the pelvic splanchnic nerves. The genital organs and lower urinary tract are controlled by the autonomic nervous system, as well as the somatic nerves. Functional issues, such as urinary incontinence and sexual dysfunction, can occur due to nerve injury during dissection.[3] In the direction of the autonomic nerves, the superior hypogastric plexus around the inferior mesenteric artery (IMA) descends along the sacral promontory and bifurcates into hypogastric nerves. The paired hypogastric nerves enter the pelvis at the level of the first sacrum and then run along the posterolateral wall of the pelvis. The pelvic (inferior hypogastric) plexus is composed of the hypogastric and pelvic splanchnic nerves originating from the second to fourth sacral spinal nerves at the lateral pelvic wall.[29-31] In this point, the Y-shaped nerve

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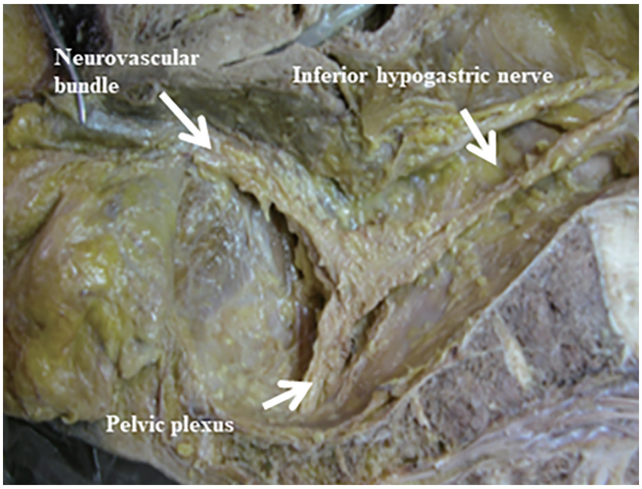

Fig. 2. Y-shaped pelvic autonomic nerve structures seen in the hemipelvis of a cadaveric section. The inferior hypogastric nerve descends along each side of the pelvic wall and merges with the sacral parasympathetic nerves to become the pelvic plexus. This plexus is densely attached to the lateral part of the mesorectal fascia, and the NVBs extend to the genitalia. Adapted from Lee et al. Ann Coloproctol 2018;34(2):59-71.[24] NVB, neurovascular bundle.

structure can be seen after removing the parietal pelvic fascia (Fig. 2).[3] Numerous fine neurovascular bundles (NVBs) originate from the pelvic plexus and descend to the urogenital organ at the lateral corner of the seminal vesicle in the 10 o'clock and 2 o'clock directions.[32] The importance of a thorough understanding of the relationship between the fascia and surrounding nerve structures, such as the inferior hypogastric nerve and the pelvic plexus, during a TME cannot be overemphasized.

Pelvic floor

In addition to knowledge regarding the fascia and autonomic nerves, an adequate understanding of the pelvic floor anatomy is essential to achieve complete rectal mobilization. In the past, pelvic floor muscles could not be visualized clearly. However, with improvements in MIS techniques, magnetic resonance imaging assessments can clearly show the anatomy of this region. The levator ani forms the pelvic floor. It consists of the pubococcygeus, iliococcygeus, and puborectalis muscles. Awareness of funnel-shaped structures is essential to achieve complete rectum mobilization (Fig. 3A). Moreover, the U-

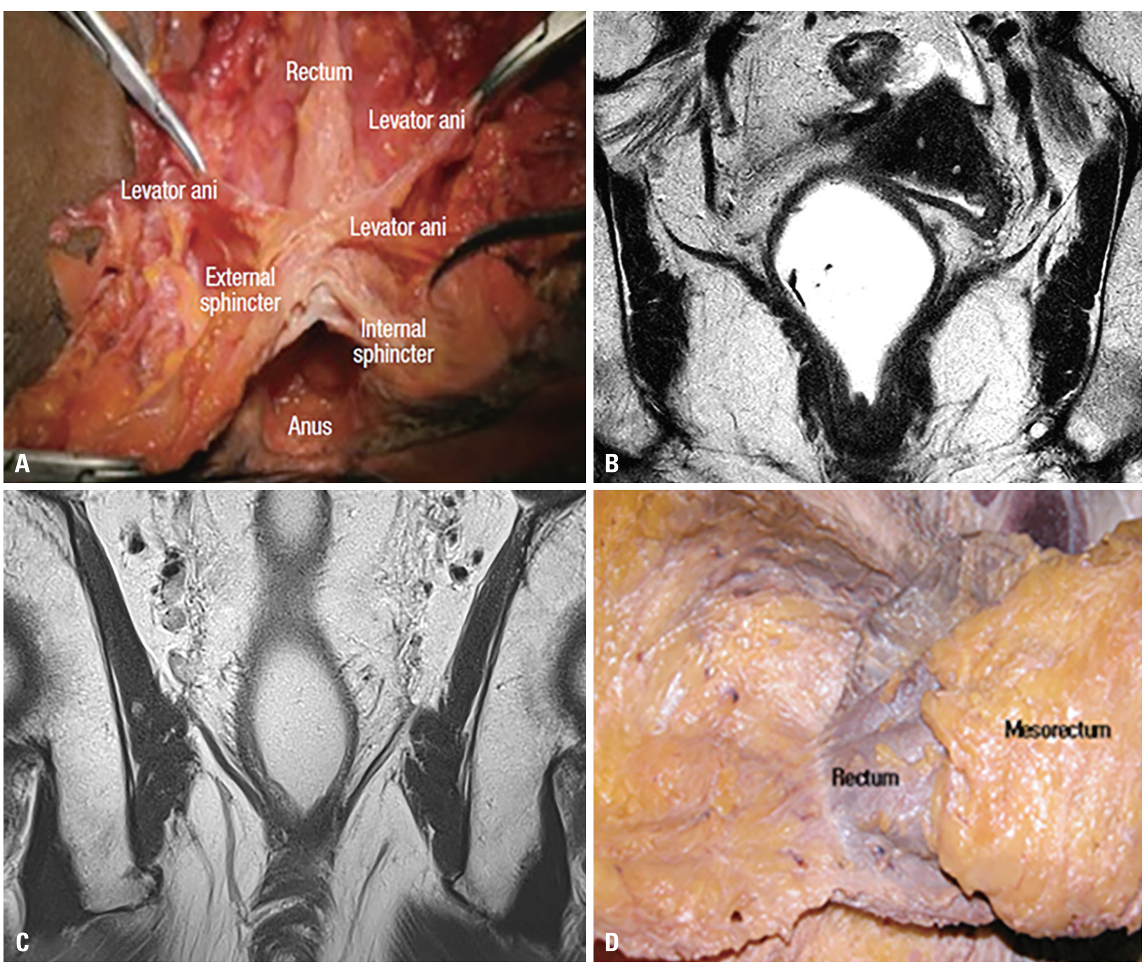

Fig. 3. Anatomy of the pelvic floor muscles. (A) The funnel-shaped pelvic floor with the sphincter complex after removal of the sacrum. Adapted from Lee et al. Ann Coloproctol 2018;34(2):59-71.[24] (B) Gradual coning down of the pelvic floor with a wide angle usually seen in women. (C) Steep coning down of the pelvic floor with a narrow angle usually seen in men. (D) The mesorectum tapered out 2 or 3 cm proximally from the pelvic floor.

shaped puborectalis muscle can be clearly seen during dissection and plays a role in preventing fecal incontinence by making a sharp anorectal angle.[33] In operative findings, the rectal muscle layer seems to be intermingled with the surrounding external anal sphincter complex. After dissection between the mesorectum and pelvic floor muscles, the anal hiatus can be identified, which is usually present 4 cm from the anal verge.[34]

We would like to emphasize two observations. First, the mesorectum is in contact with the fascia of the levator ani muscle. Moreover, the shape and angle of the funnel-shaped pelvic floor differ with patient characteristics and sex (Fig. 3B and C). The rectum and mesorectum should be usually mobilized completely from the pelvic floor, and the rectum can be resected with a secured distal resection margin. Second, the mesorectum is usually tapered out 2 or 3 cm proximally from the pelvic floor (Fig. 3D).[35]

WHAT IS THE RAINBOW TECHNIQUE?

The rainbow technique proposed by Professor Kim NK is named after the seven colors of the rainbow. This name is used to characterize the seven steps required for proper rectal mobilization. Moreover, the shape of the rainbow is similar to the TME technique used in the pelvis to avoid injury to the NVB and achieve complete TME. We have provided a comprehensive description of this surgical technique that enables preservation of these nerve structures with an intact MRF.

This method is suitable for obtaining complete TME, especially in the deep pelvis where the operative field becomes concave, deep, and narrow (Fig. 4). The boxed area represents a deep pelvic cavity. Deep pelvic dissection is performed at this area, which is crucial for oncologic and functional safety. Therefore, following an appropriate sequence of dissection and employing gentle traction and counter-traction will be necessary, and thorough anatomic knowledge will facilitate this procedure. Optimal pelvic dissection should be on the embryonic plane. In the following sections, we will discuss the rainbow method and specify the anatomical landmarks in each step. The Supplementary Video (only online) illustrates the detailed steps of the surgical procedure.

Before the rainbow method

Before performing TME for rectal mobilization, the proximal colon (sigmoid colon and descending colon) should be mobilized, and central vascular ligation and lymph node dissection should be performed. At this time, the superior hypogastric plexus (sympathetic component) is vulnerable to injury at the root of the IMA during high ligation of this artery. The pedicle of the IMA is visualized, and the lymph nodes around the IMA are cleared. The superior hypogastric plexus is carefully preserved at the root of the IMA from the abdominal aorta. It is difficult to grossly differentiate lymphatics from the nerve structure. The magnified view through a camera (laparoscopic

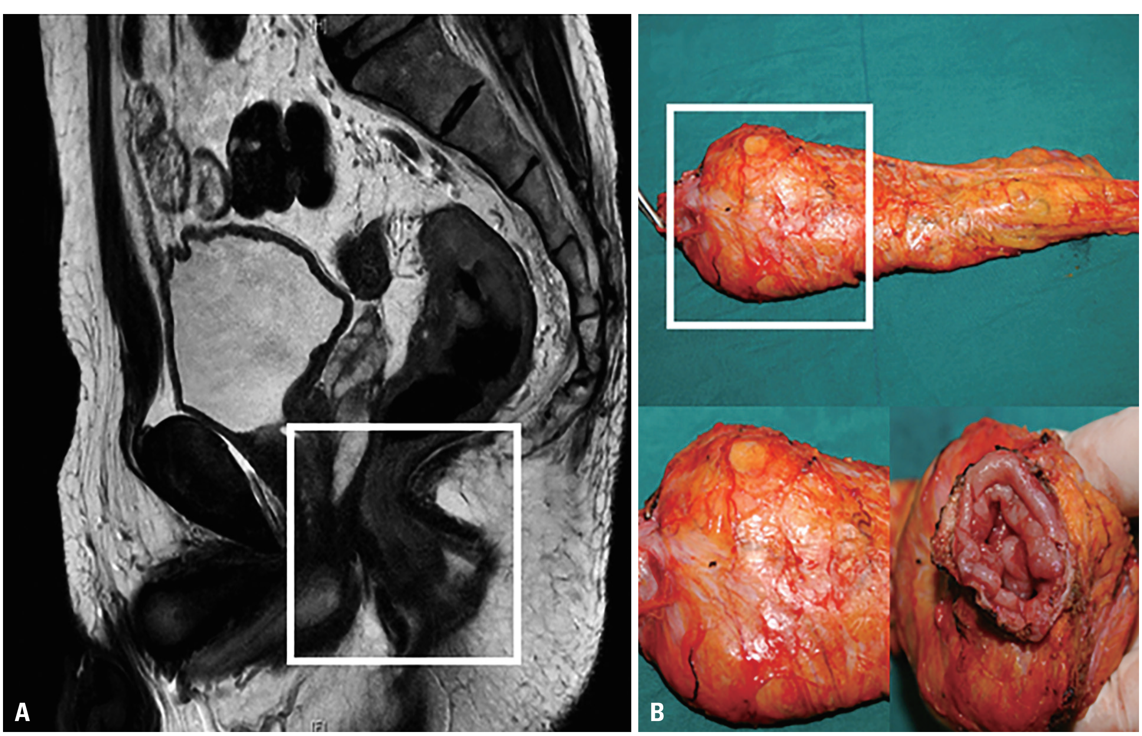

Fig. 4. Difficulty in operation in the deep pelvis. (A) Sagittal view of MRI shows the box line area, it is concave, deep, and narrow. (B) Achievement of complete TME without coning down of the mesorectum, especially in the deep pelvis, requires a standardized technique. The white square in each picture indicates the deep pelvis. TME, total mesorectal excision.

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or robotic) could be helpful in distinguishing the IMA pedicle from the underlying superior hypogastric plexus covered with the ventral fascia.[36] To preserve the superior hypogastric plexus, high ligation of the IMA should be performed 1 to 2 cm from the aorta. Low ligation of the IMA preserving the left colic artery may be performed in older patients or patients with questionable colonic blood supply.[37]

Although there has been some debate about high versus low ligation of the IMA from the perspective of oncologic safety, we personally prefer low ligation (the preservation of the left colic artery) to preserve proximal colonic perfusion and to avoid injury to the superior hypogastric plexus, since lymph node metastasis at the root of IMA is rare. When lymph node metastasis at the IMA root seems strongly suspicious in preoperative radiologic imaging, we perform high ligation; otherwise, we usually perform low ligation. In our retrospective study that compared the outcomes between high IMA ligation and low IMA ligation with dissection of lymph nodes) around the IMA origin with 1213 patients who underwent low anterior resection for stage I–III rectal cancer, there was no difference in total harvested lymph nodes and oncological outcomes between high and low ligation groups. The incidence of positive rate at the root of IMA was 2.1%.[38] The inferior mesenteric vein is usually ligated at the level of the pancreas. In some patients, a collateral artery called the arc of Riolan or the meandering mesenteric artery runs parallel to the inferior mesenteric vein to the splenic flexure and descending colon, and these arteries should be preserved to prevent colonic ischemia.[39,40]

RAINBOW TECHNIQUE

Step 1: incision of the pelvic peritoneum

Anatomical landmark: ureter, common iliac vessels

The first step in the rainbow technique is incision of the parietal peritoneum at the level of the sacral promontory caudal to the aortic bifurcation and 1–2 cm medial to the right common iliac artery and ureter. This step is performed by traction of the sigmoid colon and counter-traction and incision of the peritoneum. The same technique can be used on the left side. The lateral part of the mesorectum is separated from the underlying pelvic autonomic nerve and the parietal pelvic fascia covering the retroperitoneal structures.

After retracting the rectum to the left and incising the peritoneum, air enters the retroperitoneum and the presacral space is developed.[41] This space is completely avascular and hardly bleeds. After identification of the sacral promontory and aortic bifurcation, the surgeon should pay attention to the hypogastric nerves by pushing the retroperitoneal structures.

Step 2: posterior dissection

Anatomical landmark: inferior hypogastric nerve

The second step is the posterior dissection of the rectum. This process can be started after central vessel ligation and after completing medial and lateral dissection of the sigmoid colon. In this step, preservation of the hypogastric nerves, which are a continuation of the superior hypogastric plexus arising from T10 to L3 as a continuation of the preaortic sympathetic trunk, is important. The hypogastric nerves are two nerves on both sides that run directly over the sacral promontory about 1 cm lateral to the midline and medial to the iliac artery and the ureter.[42]

Posterior pelvic dissection is performed along the rectal proper fascia enveloping the rectum and mesorectum, leaving behind the hypogastric nerves along the pelvic sidewall. The visceral pelvic fascia is a fibrous envelope that surrounds the mesorectum and is also called the fascia propria of the rectum.[43] The dissection continues to the recto-sacral fascia.

Damage to the inferior hypogastric nerves can occur on missing the correct plane of dissection, with frequent blunt dissection, or because of uncontrolled bleeding or inadequate vision, which can result in sympathetic damage.[44] Full mobilization of the rectum is dependent on complete division of the recto-sacral fascia, and major complications like bleeding from the presacral plexus of veins can occur during this step.[27,45]

Step 3: anterior dissection

Anatomical landmark: seminal vesicle and DVF

After the anterior surface of the peritoneum is divided at the peritoneal reflection, the seminal vesicle is identified in men and the vaginal wall in women (Fig. 5A). These are important anatomical structures for anterior dissection. From the level of the seminal vesicle, DVF is a landmark structure (Fig. 5B). It is described in detail in the subsequent sections. Basically, unless the tumor directly invades the seminal vesicle, dissection should be directed below the DVF (Fig. 6). This is the optimal plane for preservation of nerves, and the dissection continues laterally along the seminal vesicles. Anteriorly directed dissection is performed only in cases of anteriorly located tumors or in cases of a suspected or threatened circumferential resection margin.[32]

Step 4: deep posterior dissection

Anatomical landmark: Waldeyer's fascia

From this point, complete TME is very difficult, since the rectum is anatomically located concavely along the curved sacrum, and both the ischial tuberosity and iliac wing limit the pelvic cavity boundary. Moreover, at the level of the anorectal junction, there remains very limited space to obtain an adequate surgical view. Although difficult, surgeons should cre-

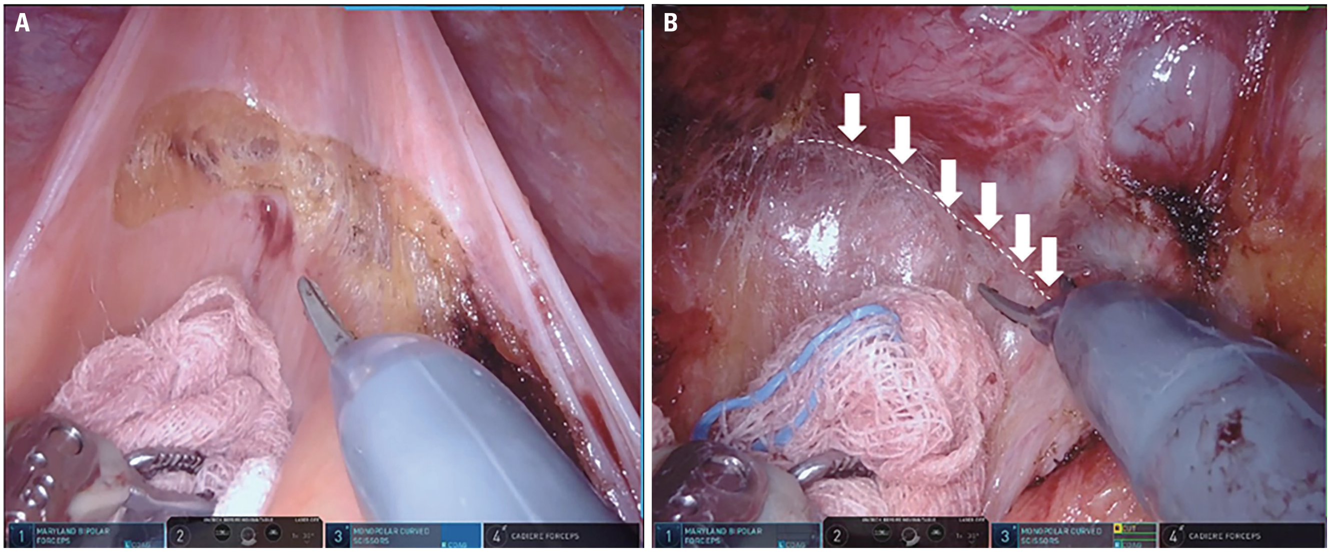

Fig. 5. Anterior dissection. (A) The anterior surface of the peritoneum is divided at the peritoneal reflection. (B) The seminal vesicle and DVF are landmark structures for anterior dissection. White arrows, DVF; white dotted line, optimal dissection plane. DVF, Denonvilliers' fascia.

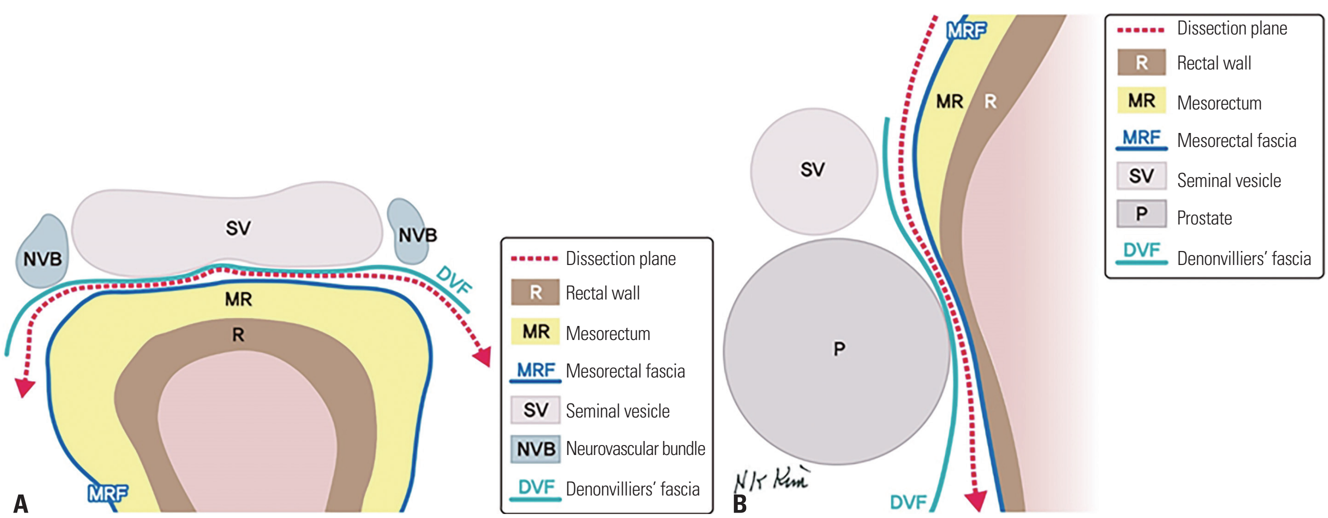

Fig. 6. Schematic images of the usual dissection plane in the anterior dissection. Unless the tumor directly invades the seminal vesicle, dissection should be directed below the DVF. This is the optimal plane for preservation of nerves, and the dissection continues laterally along the seminal vesicles. (A) Axial view. (B) Sagittal view.

ate surgical space and use dissection planes to perform sharp pelvic dissection. The lack of proper space can induce coning down and breaching of the mesorectum.

A curvilinear transverse incision, close to the rectal proper fascia, is made in the recto-sacral fascia after it is identified. Continued deep posterior dissection reveals the area where the presacral venous plexus exists and is covered with the parietal pelvic fascia. For this dissection, more constant and adequate traction are needed. This step facilitates the next step of dissection. Blunt dissection should be avoided since this maneuver may cause a partial tear and hemorrhage due to injury of the presacral venous plexus. Presacral injury is, in fact, common in open surgery. However, with the increasing use of MIS, this injury has become uncommon. A sharp division of the recto-sacral fascia is the easiest way to reach the deep pelvis and separate the rectum from the pelvic floor with its complete mobilization, especially in low-lying rectal cancers.[24,46]

There is much controversy regarding the differentiation between the "Waldeyer's fascia" and the "recto-sacral fascia or ligament." Waldeyer's fascia was defined as the presacral parietal fascia or the most caudal part of the presacral parietal fascia at its junction with the visceral fascia at the level of the anorectal junction.[47,48] Not only is it absent in a small number of cases, but its exact origin is also variable. It was noted at the level of S2 in 15% of cases, S3 in 38% of the cases, and S4 in 46% of the cases in one study.[46] In contrast, in an anatomical study, the origin of the presacral fascia was described as constant at the level of S4.[48]

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Step 5: deep anterolateral dissection

Anatomical landmark: prostate or vagina, neurovascular bundle, and pelvic plexus

Deep anterolateral dissection of the rectum constitutes the most vital and difficult step, especially in a narrow pelvis. The NVB from the pelvic plexus runs along the tip of the seminal vesicle (2 o'clock and 10 o'clock directions) and reaches the urogenital organ. In this step, NVB injury can occur easily. Deep anterolateral dissection begins from a previously incised DVF. The NVB is carefully exposed from the anterolateral aspect of the rectum. Since we dissected below the DVF, an avascular plane can be created between the rectum and mesorectum and the NVB under appropriate traction and counter-traction of the seminal vesicle. Gentle counter-traction of the seminal vesicle in the 2 o'clock direction and the NVB, especially, allows entrance into the anterolateral portion of the lower rectum, which is the gate to the deep pelvic floor (Fig. 7). When the deep anterolateral dissection reaches the pelvic floor muscle, the next step (deep posterolateral dissection) can be performed easily. However, without an adequate understanding of these structures, mesorectal tears may occur, resulting in incomplete TME and subsequent damage to the nerve structures. Therefore, this part of dissection is very important to obtain optimal oncologic and functional outcomes in the surgical treatment of middle and lower rectal cancer. In this part of the dissection procedure, a three-dimensional understanding of the structures is especially important. During this step, the MRF is separated completely from the underlying pelvic floor. Therefore, the time required for this step will differ depending on the patient's individual characteristics and sex. The presence of lateral ligaments has been a topic of debate in this context. This aspect is described in detail later. If the middle rectal artery is identified, it can be easily controlled by cauterization with monopo-

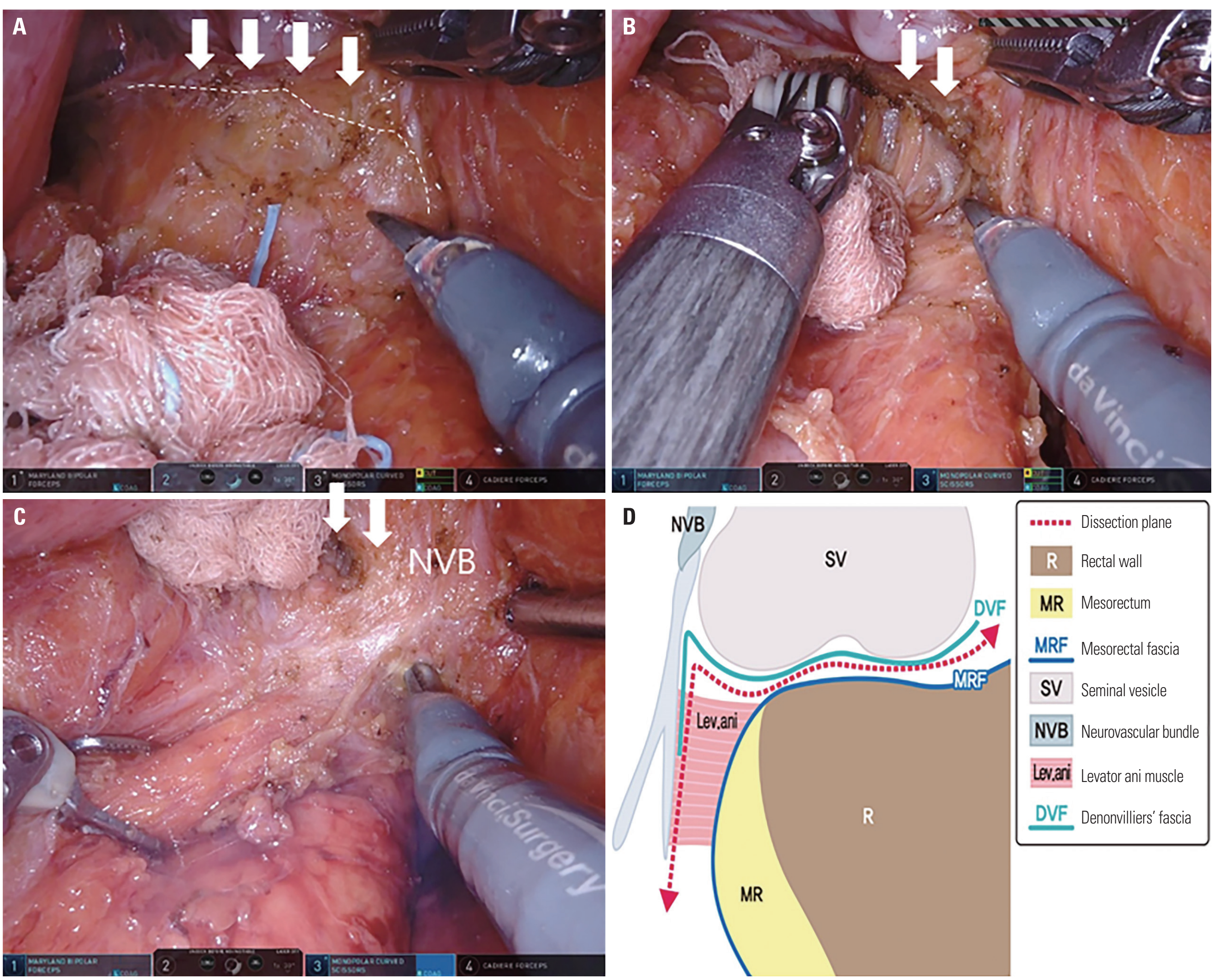

Fig. 7. Deep anterolateral dissection. (A) Deep anterolateral dissection begins from the previously incised DVF in the anterior dissection. (B) The dissection continues to the lateral side along the DVF. (C) The NVB can be exposed in the anterolateral side. (D) Schematic picture showing the dissection plane. White arrows, DVF; white dotted line, optimal dissection plane.

lar or bipolar diathermy.

Step 6: deep posterolateral dissection

Anatomical landmark: pelvic plexus, lateral attachment, and anococcygeal ligament

After finishing deep anterolateral dissection, the next step in the rainbow technique is the dissection in the deep posterolateral plane by division of the anococcygeal ligament to reach the pelvic floor posteriorly. Since deep posterior dissection and anterolateral dissection are already completed, posterolateral dissection can be easily performed along the previous dissection line (Fig. 8A). This area may contain attachments between the pelvis plexus and MRF. Therefore, gentle traction is necessary. The rainbow methods can allow safe mobilization without nerve injury. With this maneuver, the lateral aspect of the MRF is safely dissected off the pelvic plexus (Fig. 8B). At the same time, the distal mesorectum and rectum are completely separated from the NVB and the pelvic plexus. As previously mentioned, the middle rectal artery may appear occasionally during the procedure.

The appearance of the anococcygeal ligament at the dorsal aspect or both the dorsal and ventral aspects of the levator ani muscle is a topic of debate. In an anatomical study, the anococcygeal ligament was divided into two layers. The first layer was the ventral layer that was loose and rich in small and fragile vessels and extended from the presacral fascia to the conjoint longitudinal muscle layer of the anal canal. The other layer was the dorsal layer that was thin and dense and extended between the coccyx and external anal sphincter.[49] From a practical point of view, division of the anococcygeal ligament is important for complete mobilization of the rectum and enables the transection of the rectum flush with the anal canal. If the anococcygeal ligament cannot be seen in this step, it can be visualized after the mesorectum is completely mobilized from the pelvic floor.

Step 7: identification of the pelvic floor

Anatomical landmark: Puborectalis muscle, anal hiatus

The last step in the rainbow technique is the identification of the levator ani muscles after division of the anococcygeal ligament. As mentioned before, the mesorectum of the rectum is fused with the pelvic floor muscle, and the mesorectum usually tapers out 2 or 3 cm proximal from the pelvic floor.[35] The MRF can be carefully separated from the surrounding structure and deep pelvic floor. Dissection is performed carefully to identify an avascular gap between the rectal wall and pelvic floor, and traction and separation are performed from the pelvic floor. After complete dissection between the mesorectum and pelvic floor muscle, when the rectum is pulled upward, the lower rectum can be visualized without the mesorectum.

Circumferential dissection allows complete mobilization of the rectum from the pelvic floor. In the anterior side, after the rectum is mobilized from the pelvic floor and parietal pelvic fascia covering the NVB completely, anterior dissection posterior to the DVF beyond the level of seminal vesicle and rectum allows easy separation from the DVF covering the prostate gland. Pelvic dissection to the pelvic floor is a safe way to indicate an adequate distal resection margin in middle and low rectal cancer, and a stapler can be applied for proposed transection of the rectum.

Practical technical tips for the rainbow method

Brief summary: a thorough understanding of the pelvic fascia (DVF and Waldeyer's fascia), one unnamed attachment at the

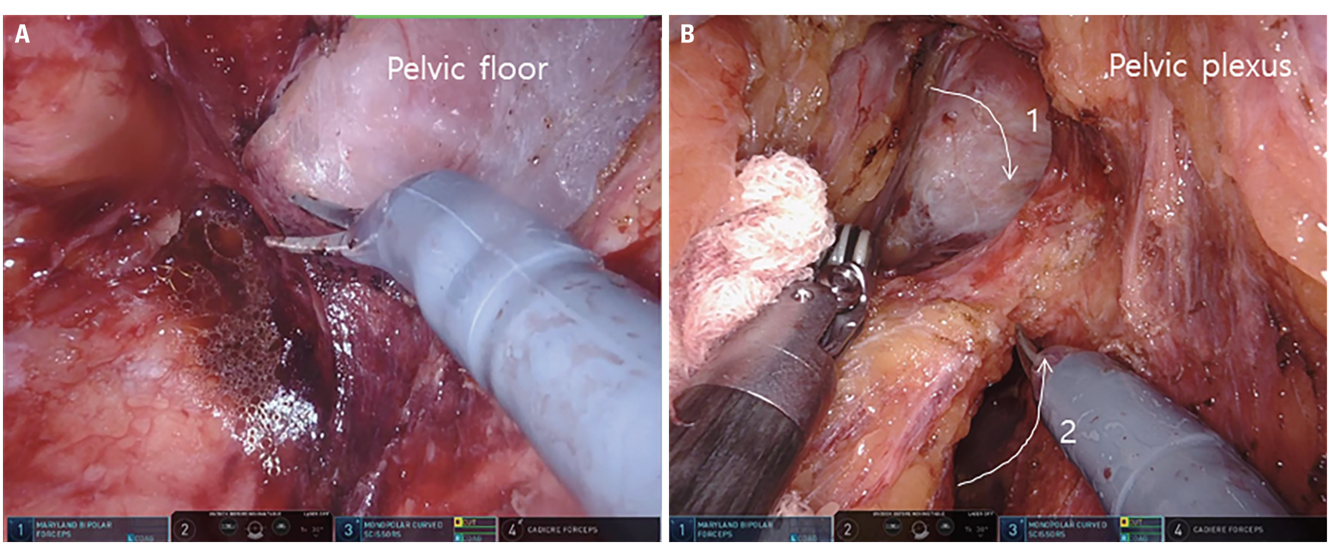

Fig. 8. Deep posterolateral dissection. (A) Dissection can be performed easily along the previous dissection line from a deep posterior dissection and deep anterolateral dissection. (B) With sequential dissection from deep anterolateral to the posterolateral last lateral attachment, the lateral side of the MRF is safely dissected from the pelvic plexus. White arrows: sequence of dissection. MRF, mesorectal fascia.

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lateral wall (including the middle rectal artery) of the mesorectum at deep pelvis, and the relationships to the pelvic autonomic nerve structures is important. For preservation of voiding and sexual function and achievement of optimal TME, sequential posterior, anterior, and lateral dissection with an understanding of the fascia structure is important. Embryonic fascia-to-fascia plane dissection is the best way to obtain a cylindrical-shaped complete TME.

We would like to emphasize the importance of deep anterolateral dissection as an essential step. After posterior dissection (Waldeyer's fascia) and anterior dissection (DVF) are completed, deep anterolateral dissection should be started from the previous DVF dissection plane. With this approach, the path to reaching the pelvic floor can be obtained without causing NVB injury (Fig. 9A and C). Moreover, in the area below the prostate level, the rectal wall, DVF, and fascia covering the NVB are stuck together. Therefore, anterior and deep antero-lateral dissection should be performed first in the lower rectum. When this step is performed successfully, the pelvic plexus can be seen clearly with deep posterior dissection (Fig. 9B and D). Subsequently, the rectum is easily separated from the surrounding fascial structure, and space can be made for more complete mobilization of the rectum. We usually dissected this area from the deep anterior, followed by the deep posterior and the lateral attachment. We believe that this approach can yield complete TME without tearing. However, some points regarding the proper surgical plane are a topic of debate.

DEBATABLE ISSUES

A thorough understanding of the anatomy of the rectum and

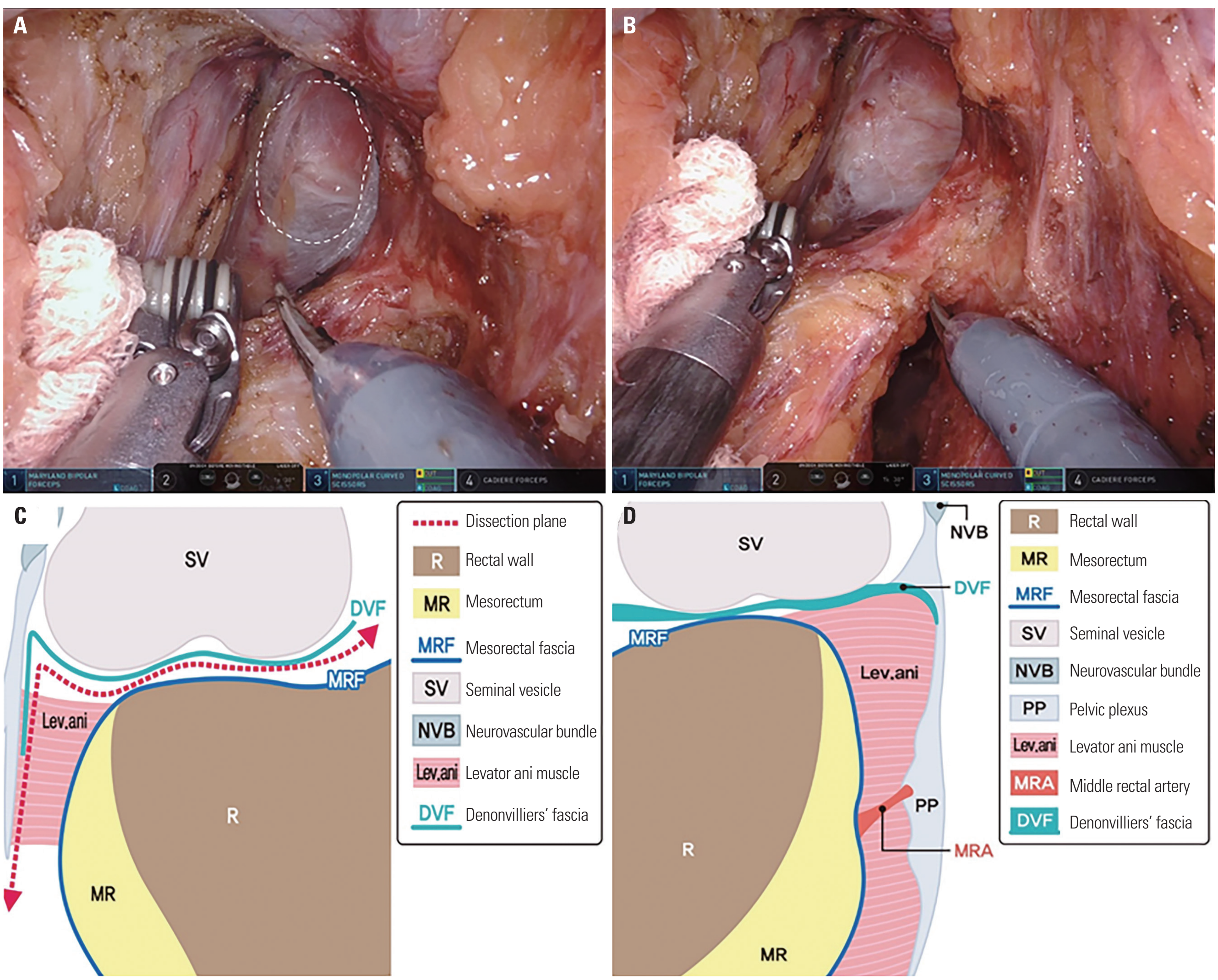

Fig. 9. Practical technical tips in the rainbow method. (A) Gentle counter-traction of the seminal vesicle in the 2 o'clock direction and the NVB allows entrance into the anterolateral portion of the lower rectum, which is the gate to the deep pelvic floor (white dotted line). (B) Deep-anterior dissection followed by deep-posterior dissection, and then, lateral attachment can yield complete TME without tearing and nerve damage. (C) Schematic picture showing the gate to the pelvic floor after deep anterolateral dissection. (D) Schematic picture showing the operation field after deep anterolateral and deep posterolateral dissection. TME, total meso-rectal excision.

surrounding relevant structures is extremely important. However, some anatomical aspects related to rectal cancer surgery have been topics of much debate. In this regard, understanding DVF and lateral attachment of the rectum from the pelvic sidewall is important for performing the rainbow method.

Denonvilliers' fascia

The DVF is a white shiny layer present anterior to the rectum and posterior to the seminal vesicles and constitutes the rectovaginal septum in women. It varies from a thin layer to a tough membrane. It is well identified in young individuals but becomes less prominent with age.[44] The anatomy of the DVF has been disputed for many years. However, its clinical implications in topographic anatomy are increasingly important for colorectal surgeons and urologists, and its relevance to the pelvic anatomy is applicable not only for oncologic outcomes but also for functional outcomes in the surgical treatment of rectal cancer and prostate gland cancer. Anatomical descriptions of the DVF are a matter of controversy, with some authors suggesting that it is more closely related to the rectum than the prostate, while Church, et al.[50] reported that it is more adherent to the prostate than the rectum. Recent studies demonstrated that DVF has multilayers that are more prominent in men than in women.[51] Xu, et al.[52] reported confocal microscopic findings showing the pre-rectal space and the presence of an optimal plane that was posterior to the multilayered DVF. In a micro-CT study, which was the first to use this technique in the cadaveric rectum, we could identify that DVF was located anteriorly and more attached to the prostate (not published).

The choice between dissection planes (anterior or posterior to DVF) has been a topic of debate. Heald and Moran.[47] argued that dissection posterior to DVF is oncologically inadequate and may be difficult, but dissection in the anterior plane, which is called the extramesorectal plane, is optimal and natural. Kraima, et al.[28] also supported this recommendation. They suggested that DVF is adherent to and continuous with the MRF, so the optimal surgical dissection during TME would be anterior to DVF to ensure radical removal. In contrast, Lindsey and Mortensen,[53] Peschaud, et al.,[54] and Fang, et al.[55] reported that the optimal plane for anterior rectal mobilization is posterior to DVF. Recently Zhang, et al.[56] proposed two layers of the DVF based on a cadaveric study: the posterior layer was a direct extension of the proper rectal fascia, and the anterior layer extended to the presacral fascia, which is considered to not be a part of the surgical plane. We agree with Dr. Zhang's observations regarding the perirectal fascia and spaces. In our experience, unless the tumor directly invades the seminal vesicle, dissection should be directed below the DVF (Fig. 10A). This is the optimal plane for preservation of nerves, and the dissection continues laterally along the seminal vesicles. Dissection anterior to DVF is associated with a high risk of nerve injuries, as well as intraoperative bleeding, and should be resorted to only in cases of anteriorly located tumors or in cases of a suspected or threatened circumferential resection margin (Fig. 10B). Moreover, DVF appears as a multilayer at seminal vesicle levels, but at the prostate level, it appears as one hard layer. Therefore, we suggest that customized excision of the DVF according to the tumor location and extent of tumor invasion is necessary. If there is an anteriorly located T3 tumor only at the level of the seminal vesicle, we would prefer to perform dissection anterior to the DVF and beyond the SV and placed posterior to DVF at the prostate (Fig. 10C). Customized dissection to the DVF according to the tumor level and clinical T stage is believed to have both oncologic and functional significance.

Middle rectal artery and lateral attachment of the rectum

The presence of lateral ligaments has been a topic of much controversy. They are thought to be a fascial condensation on both anterolateral aspects of the extraperitoneal rectum.[57-59] In past studies, there was some concern about the bleeding from middle rectal artery when the rectum was mobilized from the lateral pelvic wall. In the open TME period, this part of dissection was performed manually because of the lack of visibility

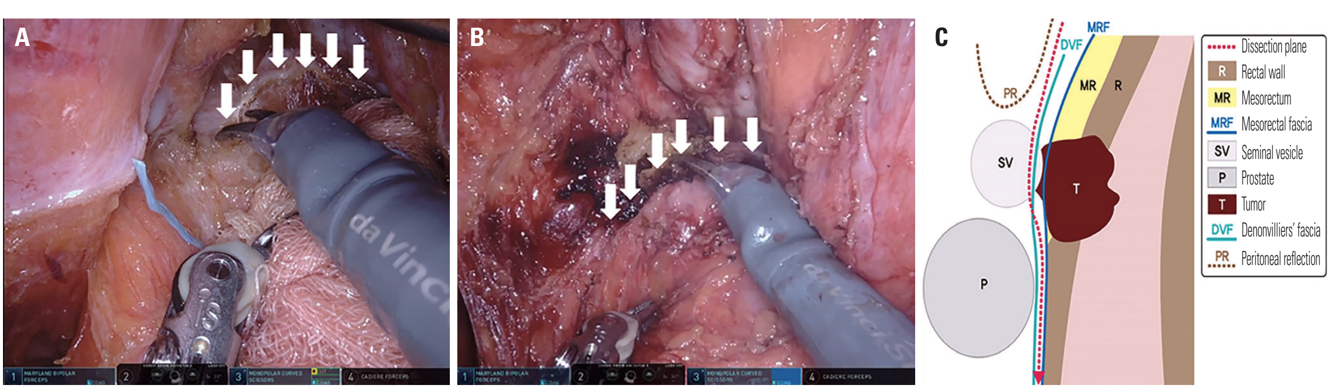

Fig. 10. Customized excision of the DVF according to the tumor location and extent of tumor invasion. (A) Unless the tumor directly invades the seminal vesicle, dissection should be directed to below the DVF. (B) Dissection performed anteriorly is resorted to only in cases of anteriorly located tumors or in cases of a suspected or threatened circumferential resection margin. (C) Schematic picture showing the dissection plane in anteriorly located T3 rectal cancer only at the level of seminal vesicle. White arrows: DVF.

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and inadequate understanding of anatomic structures among practicing surgeons. At that time, the lateral attachment was usually clamped and ligated with excessive traction, leading to the possibility of nerve damage. With advancements in laparoscopic and robotic surgery, most middle rectal arteries can be clearly identified under direct vision, and the frequency of middle rectal arteries has been reported to range from 12% to 97%. These are also usually divided in lateral and anterolateral types.[60] They usually penetrate the pelvic plexus from the lateral side along with the MRF.[59,61] Therefore, appropriate gentle handling of these structures is crucial for ensuring an optimal surgical plane and pelvic autonomic nerve preservation. Traditionally, this area was called the lateral attachment, with the middle rectal artery being considered as the main structure in the lateral attachment that penetrates the pelvic plexus to enter the rectum from the lateral direction. The lateral attachment has been regarded as the spot where the rectum is attached to the lateral pelvic wall. However, Jones, et al.[57] performed a precise anatomical investigation of the lateral ligament and concluded that the traditionally recognized lateral ligament was not actually present, an observation with which we agree. According to their study, the diameter of the middle rectal artery ranged from 1 to 2.5 mm, and the rate of bilaterality ranged from 20% to 61%. If the middle rectal artery is identified, it can be easily controlled by cauterization with monopolar or bipolar diathermy (Fig. 9B and D).

CONCLUSIONS

Over 30 years of surgical practice at Severance Hospital, we have gained much anatomical knowledge of the rectum and related anatomical structures in the deep pelvic cavity. In addition to the insights on optimal pelvic dissection gained during operations, we have gained more information from radiologic and cadaveric studies. We have used these insights to improve the functional and oncologic outcomes in the surgical treatment of rectal cancer. On the basis of our experience, we would like to propose the rainbow method for proper rectal mobilization according to the anatomical parameters of the rectum, mesorectum, and pelvic fascia without nerve damage. We would like to call this step-by-step procedure as the rainbow method since a rainbow symbolizes promise and hope. We strongly believe this sequence of anatomical dissection can provide optimal outcomes of surgical treatment for rectal cancer. The benefits of this method include achievement of complete TME and preservation of the NVB. We believe our standardized technique is safe and effective, and we hope that this method will improve surgical outcomes.

The primary requirement for performing the rainbow method is a thorough understanding of the pelvic fascial structures, the anatomy of the deep pelvis, and the anatomy of nerve structure. In particular, an understanding of the DVF is especially important. The development and anatomy of the DVF have been a topic of debate for many years and have led to confusion regarding its operative surgical appearance. A good understanding of the anatomy of pelvic autonomic nerves and a meticulous surgical technique can prevent inadvertent nerve damage. We strongly believe every colorectal surgeon should be a master surgeon because they can help rectal cancer patients become free of disease and maintain a good quality of life.

SUPPLEMENTARY DATA

Video 1. Step-by-step approach (Incision of the pelvic peritoneum-Posterior dissection-Anterior dissection-Deep posterior dissection-Deep anterolateral dissection - Deep posterolateral dissection-Identification of the pelvic floor) of the Rainbow method using da Vinci Xi robotic system.

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AUTHOR CONTRIBUTIONS

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