Radiology

The Use of MR Imaging in Treatment Planning for Patients with Rectal Carcinoma: Have You Checked the "DISTANCE"?[1]

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Rectal cancer is a common and serious disease in the Western hemisphere. Optimal treatment of rectal cancer involves a multidisciplinary approach, with collaboration required between radiologists, oncologists, surgeons, and pathologists to achieve local control and decrease the rate of recurrence. Several studies have been published that show the ability to accurately stage rectal cancer with magnetic resonance (MR) imaging. Moreover, advances in preoperative therapies require accurate preoperative staging with MR imaging to select those patients who may benefit from more intensive treatment, without subjecting those who will not benefit to unnecessary treatment. As we enter an era of individualized patient care, stratified according to the risk of both local and distant failure, imaging takes on the same importance as the tumor type and genetic susceptibility. MR imaging is now an essential tool to enable the oncology team to make appropriate treatment decisions. However, rectal cancer evaluation with MR imaging remains a challenge in the hands of nonexperts. This article describes a mnemonic device, "DISTANCE," to enable a systematic approach to the interpretation of MR images, thereby enabling all the clinically relevant features to be adequately assessed: DIS, for Distance from the Inferior part of the tumor to the transitional Skin; T, for T staging; A, for Anal complex; N, for Nodal staging; C, for Circumferential resection margin; and E, for Extramural vascular invasion.

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Learning Objectives:

After reading the article and taking the test, the reader will be able to:

- Discuss the role of new MR techniques in rectal cancer staging.
- Describe how imaging is used to guide surgical and radiation planning.
- Use a structured report to accurately assess what clinicians need to know from radiologists in rectal cancer staging.
- Discuss the pitfalls in interpretation of images.

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In the United States, colorectal cancer is the third most common cancer in men after prostate and lung and the second most common in women after breast cancer (1). One-third of colorectal cancers occur in the rectum (1). Recent population data show that the survival rates for rectal cancer have improved and surpassed those of colon cancer when compared with rates in the year 1995. This trend has been attributed to the combined effects of better staging, improved preoperative treatment strategies, and total mesorectal excision (TME) surgery (1). Despite the major improvements that have been made due to TME (2), management of rectal cancer still remains a challenge (3). The use of chemotherapy and radiation therapy (CRT) followed by TME has been widely adopted for the management of locally advanced rectal cancers because this approach increases the probability of anal sphincter preservation and decreases the local recurrence rate (4). As we enter the era of personalized medicine, with therapies stratified according to the risk of local or distant recurrence, imaging has become an essential tool in the preoperative decision making to avoid both under- and overtreatment. In addition, there is increasing desire for more selective use of preoperative radiation therapy due to decrease morbidity. This requires a full understanding of the disease, as well as a full understanding of what effect false-positive or false-negative findings can have on treatment choices and outcome. However, rectal cancer evaluation with magnetic resonance (MR) imaging is a challenge in nonexpert hands. Radiology reports generally lack specific detail as pertains to cancer staging and preoperative risk assessment. Recently, Pedersen et al (5) reported the results of a clinical audit of a postgraduate multidisciplinary development program for the interpretation of pelvic MR images. In this study, the authors showed that report quality could be significantly improved by introducing a standardized form. In a review, Taylor et al (6) reported a form-based reporting tool that enables a systematic approach to the interpretation of MR images in patients with rectal carcinoma. We encourage the use of a dedicated form to enable consistent documentation of the preoperative prognostic factors. We have also created a mnemonic to help radiologists use a systematic approach to the interpretation of rectal MR imaging. We proposed the mnemonic "DISTANCE" in this way.

Essentials

- Rectal cancer T stage must be assessed on planes strictly perpendicular to the long axis of the rectum at the level of the tumor; incorrect plane of acquisition leads to blurring of the muscularis propria and may lead to overstaging.
- The depth of extramural spread is a key factor in determining prognosis and stratifying patients for preoperative therapy.
- A positive margin is defined as tumor lying within 1 mm of the mesorectal fascia.
- Positive margins can be due to tumor deposits, main tumor extension, extramural vascular invasion, or suspicious lymph nodes.

MR Imaging Technique

Rectal MR imaging is best performed with phased-array surface coils.

Patient Preparation

Rectal gel can be helpful to visualize the intraluminal component of the tumor, particularly if the patient has a small polypoid lesion. It is important not to overdistend the rectum with rectal gel since this will distort the anatomy and reduce the ability to interrogate the surrounding mesorectum, which will be compressed by overdistension. Rectal distension reduces the distance between the rectal wall and the mesorectal fascia and may affect the ability to accurately determine the distance between the tumor and the potential resection margin on MR images (7). The majority of rectal carcinoma tumors produce mucous, which enables similar visualization of the intraluminal component (8).

We routinely administer a spasmolytic agent (butylscopolamine) at a dose of 40 mg to prevent artifacts caused by peristalsis of the small bowel. The agent has a short half-life when administered intravenously and is therefore injected intramuscularly immediately prior to placing the patient on the MR imaging table.

The patient is positioned supine, and a phased-array surface coil is placed on the pelvis in such a way that the lower edge of the coil lies below the pubic bone. For low rectal tumors, the lower edge must lie at least 10 cm below the symphysis pubis and the upper edge should be no higher than the sacral promontory.

For this reason, it is absolutely essential that the referring surgeon has accurately communicated the tumor position (low, mid-, or high rectal) for appropriate coil placement and planning of the sequences.

Protocol

Figure 1 summarizes our MR protocol. The main pulse sequence is a thin-section (3-mm) T2-weighted fast spin-echo sequence performed in a plane orthogonal to the tumor (9). With this sequence, it is possible to precisely evaluate the tumor and its relationship to the intestinal wall, mesorectal fascia, and the pelvic organs. Indeed, an incorrect plane of acquisition leads to volume averaging of the muscularis propria and may lead to overstaging. Placement of the orthogonal plane is based on the tumor location on the sagittal T2-weighted images.

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Abbreviations:
CRM = circumferential resection margin
CRT = chemotherapy and radiation therapy
DW = diffusion weighted
EMVI = extramural vascular invasion
TME = total mesorectal excision

Conflicts of interest are listed at the end of this article.

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Figure 1

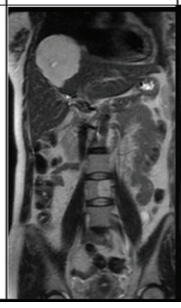
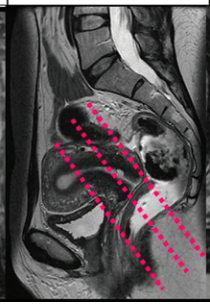
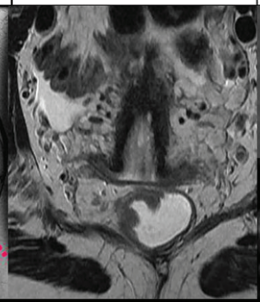
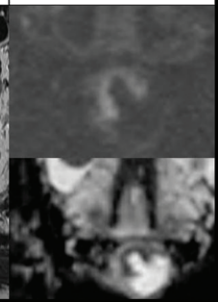
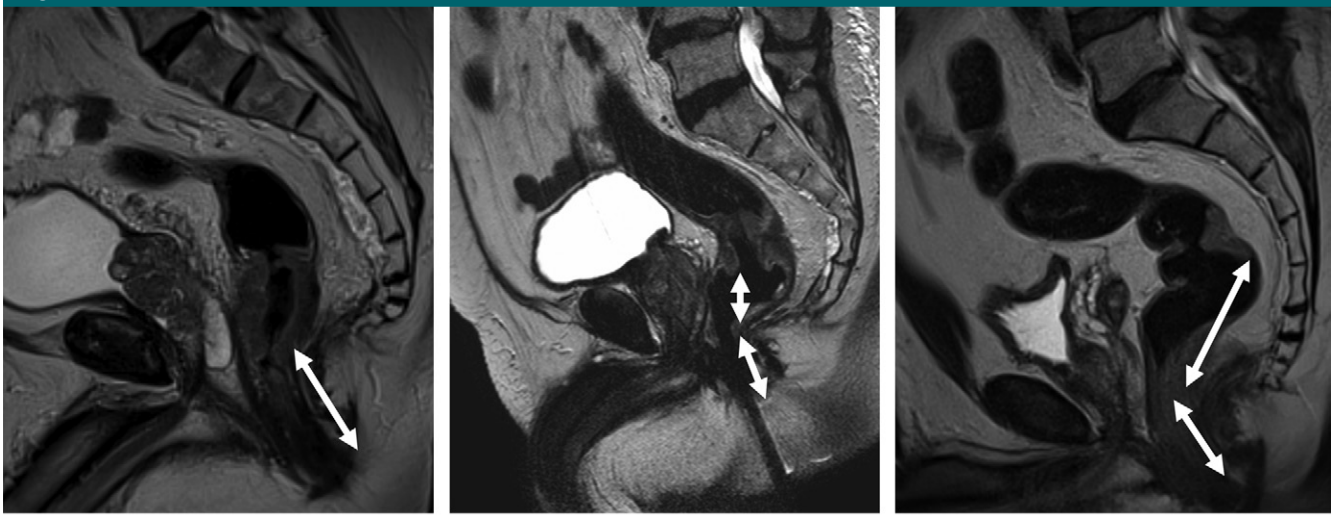
	Coronal SSFSE BH	Sagittal FRFSE T2	Short axis oblique FRFSE/T2	DWI B=500/1000
TR	2000	2800	4000	5000
TE	83.33	101	102	Min
ET	1	17	17	
FOV	44	24	16	28
MATRIX	256x192	512x256	256X256	128X256
Slice thickness Gap	5mm/6mm	4mm/1mm	3mm/0	6mm/1mm
Technical note	Must include the whole liver	**Coil positioning:** optimally centered for adequate coverage of rectum, mesorectum, and sphincter complex. It is crucial to cover the lymph node draining territory, which is **5 cm** above the tumor.	Must be performed **perpendicular** to the long axis of the rectum at the level of the tumor	
Pitfalls		**Tumor not visible on sagittal sequence** : it may be necessary to obtain high-resolution images along the entire length of the rectum	**•Motion artifacts :** -Bowel, bladder artifacts → fasting, empty bladder prior entering the MR, antispasmodics -Respiratory artifacts → fat saturation band -Motion artifacts → swapping phase and frequency encoding directions	
Interest	•OPTIONAL •Incidental findings •Metastatic disease detection	•Tumor **location** •**Height** from anal verge •Relationship to peritoneal reflection	•**T** staging and **N** detection •Chemoradiotherapy (CRT) evaluation •**Extramural Vascular Invasion (EMVI)**	•Detection of **EMVI** and **nodes** •CRT evaluation •Must be associated with T2 images
EXAMPLE				

Figure 1: Imaging protocol performed with our 1.5-T MR imager. *ET* = echo train length, *FOV* = field of view, *FRFSE* = fast-recovery fast spin echo, *Min* = minimum, *SSFSE BH* = single-shot fast spin-echo breath hold, *TE* = echo time (msec), *TR* = repetition time (msec). Red lines indicate orthogonal plane to the tumor in order to perform short-axis oblique sequence.

We offer the following clues for acquiring images in the axial plane perpendicular to the tumor: *(a)* When the tumor is small and/or difficult to see, the tumor may be visible only on the high-spatial-resolution images and it may be necessary to perform high-spatial-resolution imaging along the entire length of the rectum. Moreover, in our experience, rectal gel may be helpful under these circumstances. *(b)* Some patients may present with a tortuous rectum; repeated acquisitions in the axial plane perpendicular to the change in rectal angulation can be useful. *(c)* In contradistinction to small lesions, the center/origin of the tumor from the rectal wall of large lesions may be difficult to assess in the sagittal plane; again, repeated acquisitions in the axial plane perpendicular to the long axis of the tumor may be useful.

For patients with low rectal cancers, high-spatial-resolution T2-weighted fast spin-echo coronal imaging is added to optimally depict the levator muscles, the sphincter complex, the intersphincteric

Figure 2



a. b. c.

Figure 2: Sagittal T2-weighted images in different patients with rectal carcinoma show distance (arrows) from the anal verge in **(a)** low rectal, **(b)** midrectal, and **(c)** upper rectal tumors (low rectal tumor, <5 cm; midrectal, 5–10 cm; upper rectal, >10 cm). The measurement must be performed in a relatively straight line to produce similar measurement to that undertaken with rigid sigmoidoscopy.

plane, and the relationship to the rectal wall.

Mesorectal nodes are studied by using the axial high-spatial-resolution T2-weighted images for assessment of both nodal involvement and the relationship with the mesorectal fascia. The coronal oblique and small-field-of-view axial images also cover the pelvic sidewall, thereby enabling accurate preoperative identification of patients with high-risk malignant pelvic sidewall lymph nodes that would benefit from preoperative radiation therapy and/or selective pelvic sidewall dissection (10).

Finally, we recently added diffusion-weighted (DW) imaging to our imaging protocol. In our experience, DW imaging does not have sufficient resolution to determine the precise depth of extramural spread nor sufficient sensitivity and specificity to improve nodal staging. However, DW imaging can be helpful in detection of extramural venous invasion, in localization of lymph nodes, and in response assessment after CRT.

Since assessment of tumor extent on the T2-weighted images is based on the intrinsic contrast between the high-signal-intensity mesorectal fat and the rather low signal intensity of the tumor, spectral fat suppression techniques are not recommended because this severely limits the ability to delineate the tumor.

Our own experience supports the current data in the literature that suggest that intravenous contrast medium administration does not improve the accuracy of staging rectal tumors with MR imaging (11,12). Therefore, contrast-enhanced sequences are not routinely performed, and there is no evidence to suggest that extent of tumor invasion is improved with intravenous contrast medium.

MR Image Interpretation: Mnemonic "DISTANCE"

DIS: Distance from Inferior Part of Tumor to Transitional Skin

The level of the tumor is given from the anal verge (distal end of the anal canal, forming a transitional zone between the skin of the anal canal and the perianal skin) because this is a useful reference point for surgeons. It is measured from the most caudal aspect of the raised rolled edge of the tumor to the anal verge (Fig 2). Traditionally the rectum has been divided into thirds since outcomes and surgical management are affected by the location of the tumor (Fig 2):

Upper.—The lowest edge of the tumor is more than 10 cm from the anal verge. The anterior wall of the upper rectum is covered by the peritoneal reflection; the risk of peritoneal perforation in upper rectal tumors is high, and a warning to the surgeon will enable careful dissection to minimize the risk of tumor spillage. Moreover, the point of peritoneal reflection attachment occurs at a variable height, particularly in women, and can be as low as 5 cm from the anal verge. Careful assessment of the peritoneal reflection must be performed in upper rectal tumors.

Middle.—The lowest edge of the tumor is located between 5 and 10 cm from the anal verge. This segment of the rectum, which lies below the peritoneal reflection, is completely encircled by mesorectum and will therefore be suitable for TME. The surgical margins will be formed by the mesorectal fascia; this is the plane of dissection in TME surgery.

Lower.—The lowest edge of the tumor is less than 5 cm from the anal verge. At this level, the mesorectum tapers

Figure 3

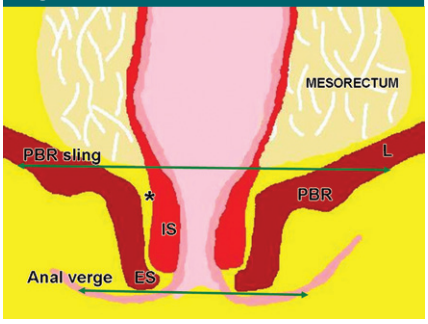


Figure 3: Low rectal anatomy schematic shows the internal sphincter *(IS)* as thickening and continuation of the circular muscle layer of the rectum. The external sphincter *(ES)* complex is composed of the continuation of the inferior portion of the levator ani muscle *(L)* and the puborectalis muscle *(PBR)*. Below the puborectalis sling there is no mesorectum, which for higher lesions acts as a protective barrier to contain tumor spread. Note that the intersphincteric space (*) is only of few millimeters in width.

Figure 4

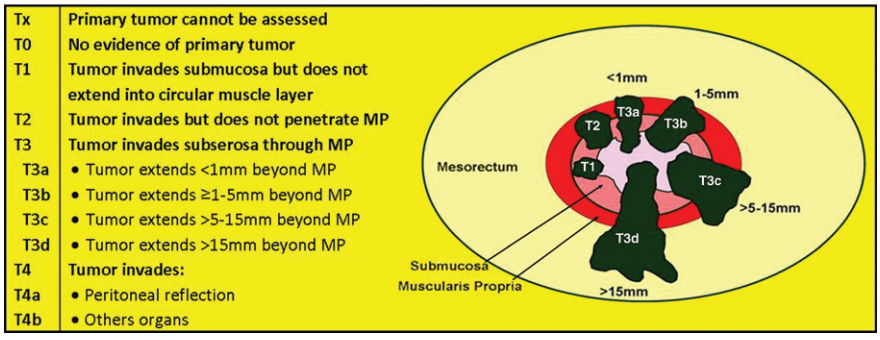


Figure 4: Rectal tumor T staging on MR images according to Smith and Brown (21). The new clinical staging classification from the American Joint Committee on Cancer differs slightly from the MR imaging classification: T3a, <5 mm; T3b, 5–10 mm; T3c, >10 mm. *MP* = muscularis propria.

sharply. Anteriorly the mesorectal fascia fuses with the remnant of the urogenital septum. This is a dense fascia band (rectoprostatic fascia in the male; rectovaginal septum in the female). The anorectal junction is held forward by the puborectal sling. At the anorectal junction, the muscularis propria of the rectum changes: The circular layer thickens and becomes the internal sphincter. The external sphincter complex is composed of the most inferior part of the levator ani muscle, the puborectalis sling, and the external sphincter muscles. Submucosal apposition of the two sphincters in the lower anal canal gives rise to the palpable intersphincteric groove (Fig 3).

The upper border of the puborectalis sling forms the upper edge of the surgical anal canal. Evaluation of the relationship of the tumor to the upper margin of the puborectalis sling assists in the presurgical determination of whether sphincter-sparing resection is feasible.

T: T Staging

The overall reported accuracy for T staging by using a pelvic phased-array coil ranges from 59% to 95% (9,13,14). The identification and staging of rectal cancers at MR imaging is largely based on differences in T2 signal intensity between the tumor, submucosa, muscular layer, and mesorectum. While T1 rectal carcinomas are confined to the mucosa and submucosa, T2 tumors invade the muscularis propria and T3 lesions extend beyond.

Most staging failures occur in the differentiation between T2 and borderline T3 lesions (15). Indeed, it is sometimes difficult to distinguish true mesorectal tumor invasion from desmoplastic reactions (9,15). In the authors' experience, staging failures can frequently be attributed to the use of thicker sections and lower resolution techniques, as well as a lack of understanding of the morphology of desmoplastic reaction compared with tumor. Although morphologically dissimilar, this difference is not routinely appreciated by using low-resolution images. Desmoplasia associated with ulcerating tumors at the invasive border is typically seen as fine low-signal-intensity spicules. Tumor extension into the mesorectum, on the other hand, forms thicker, intermediate-signal-intensity nodular bands. Clinically and therapeutically, it is much more important to measure the depth of extramural spread in millimeters than to give the T stage, since a T2 tumor has exactly the same prognosis as a T3 tumor with less than 1 mm spread. A number of histopathologic studies have shown that T3 tumors with more than 5 mm mesorectal invasion have a cancer-specific 5-year survival rate of approximately 54%. On the other hand, for tumor spread of 5 mm or less, the cancer-specific survival exceeds 85% (16,17). The MERCURY study group (Magnetic Resonance Imaging and Rectal Cancer European Equivalence) showed that there was excellent correlation between the depth of extramural spread and histopathologic results (18). In a separate study undertaken by Danish radiologists, performance and reproducibility of measuring the depth of extramural spread was much greater than measurement of the considerably larger distances to the mesorectal fascia (19).

Therefore, it is not the 1-mm distinction between T2 and T3 that may potentially govern treatment decisions, but the robust identification of high-risk patients whose risk of metastatic disease increases steadily with each millimeter of spread beyond 5 mm. The depth of extramural spread is a key factor in determining prognosis and stratifying patients for preoperative therapy. The more recent clinical staging classification from the American Joint Committee on Cancer (2010) now takes into account the subclassification of T3 tumors (20). It differs slightly from the MR imaging classification (Figs 4, 5) (21).

A second pitfall is the distinction between T3 and T4a lesions owing to peritoneal invasion. The identification of the peritoneal attachment and its involvement is important because tumors with peritoneal reflection invasion (T4a) may require preoperative radiation therapy (Fig 6). Moreover, these tumors should

Figure 5

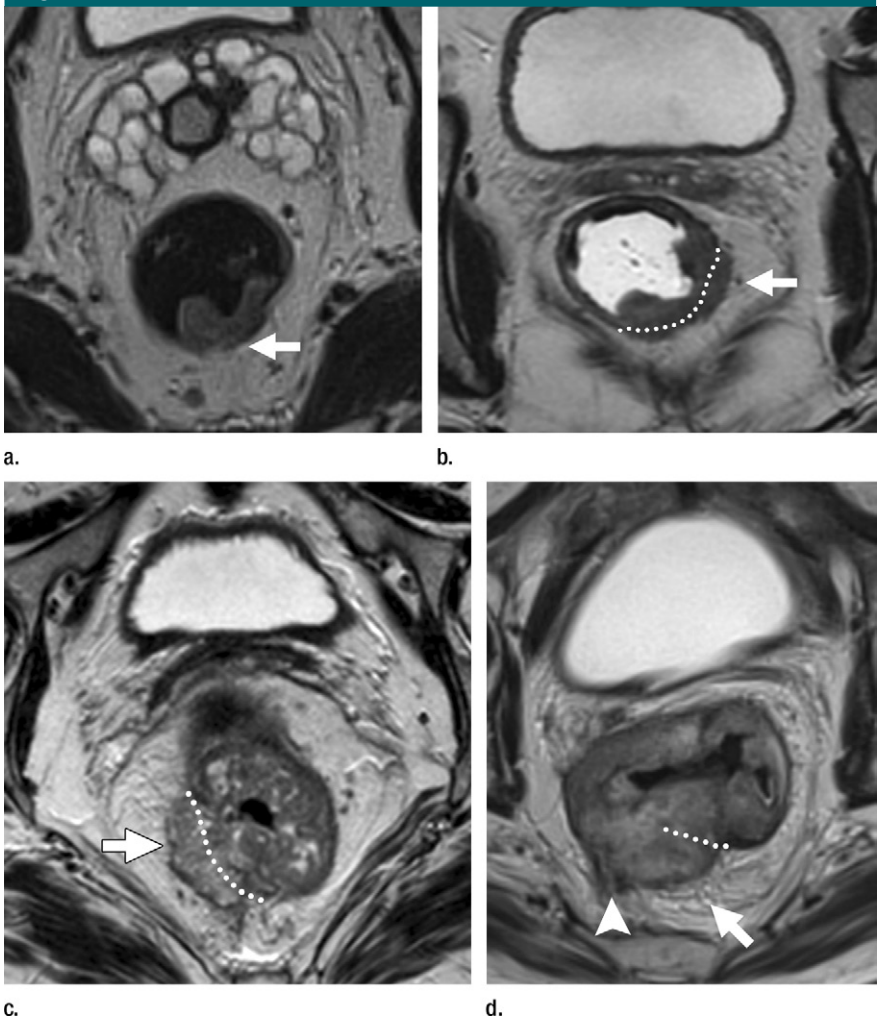


Figure 5: Short-axis axial high-spatial-resolution T2-weighted images of different subclassifications of T3 tumors extramural spread (arrow) according to Smith and Brown (21): **(a)** T3a (<1 mm), **(b)** T3b (1–5 mm), **(c)** T3c (>5–15 mm), and **(d)** T3d (greater than 15 mm). Arrowhead = mesorectal involvement. Dashed line = muscularis propria border.

Figure 6

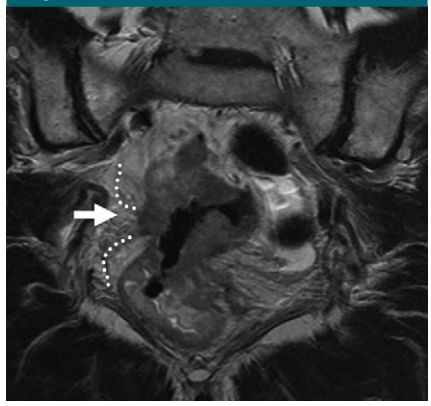


Figure 6: Coronal high-spatial-resolution T2-weighted image of a stage T4a tumor. Anterior dashed line outlines peritoneal reflection, which is partially involved by tumor (arrow) (posterior dashed line outlines the mesorectal fascia).

be reported at MR imaging as circumferential resection margin (CRM) negative because CRM corresponds to the cut surgical resection margin and does not cover the anterior aspect of the upper rectum. The surgeon cannot influence the free peritoneal surface; the surgical resection margin will be negative, since the whole rectum will be excised. However, a T4a tumor in this area potentially sheds cells into the rectovesical space or pouch of Douglas and increases the risk of pelvic recurrence.

The following are diagnostic clues at the workstation for T staging:

1. T stage must be assessed on planes strictly perpendicular to the tumor. Incorrect prescription of the acquisition plane leads to blurring of the muscularis propria and may lead to overstaging.

2. In differentiating between stage T2 and T3 tumors, the crucial criterion is involvement of the perirectal fat. In stage T3, the muscularis propria is completely disrupted and cannot be clearly distinguished from the perirectal fat: The tumor spreads beyond the muscularis propria into the perirectal fat with a broad-based bulge or nodular appearance.

3. Outer longitudinal layer of the muscularis propria can be focally disrupted by small vessels penetrating the wall; this does not necessarily indicate tumor invasion.

4. The depth of extramural spread must be measured in millimeters beyond the outer edge of the longitudinal muscular layer and recorded according to Smith and Brown (Figs 4, 5) (21).

5. Peritoneal reflection must be assessed in upper rectal tumors. It may be identified on sagittal T2-weighted images as a low-signal-intensity linear structure that can be seen extending from the posterior aspect of the dome of the bladder to the ventral aspect of the rectum. On axial images, the point of attachment has a v-shaped configuration (Fig 6).

6. Peritoneal involvement (T4a) does not equate to CRM involvement.

A: Anal Complex—Sphincters and Puborectal Muscles

Low rectal tumors are associated with higher rates of positive resection margins, higher local recurrence rates, and poorer survival (22). This is largely due to anatomic considerations and the fact that the mesorectal envelope tapers downward at this level.

Pretreatment MR imaging must be able to allow us to define the location of the tumor relative to the sphincter com-

Figure 7

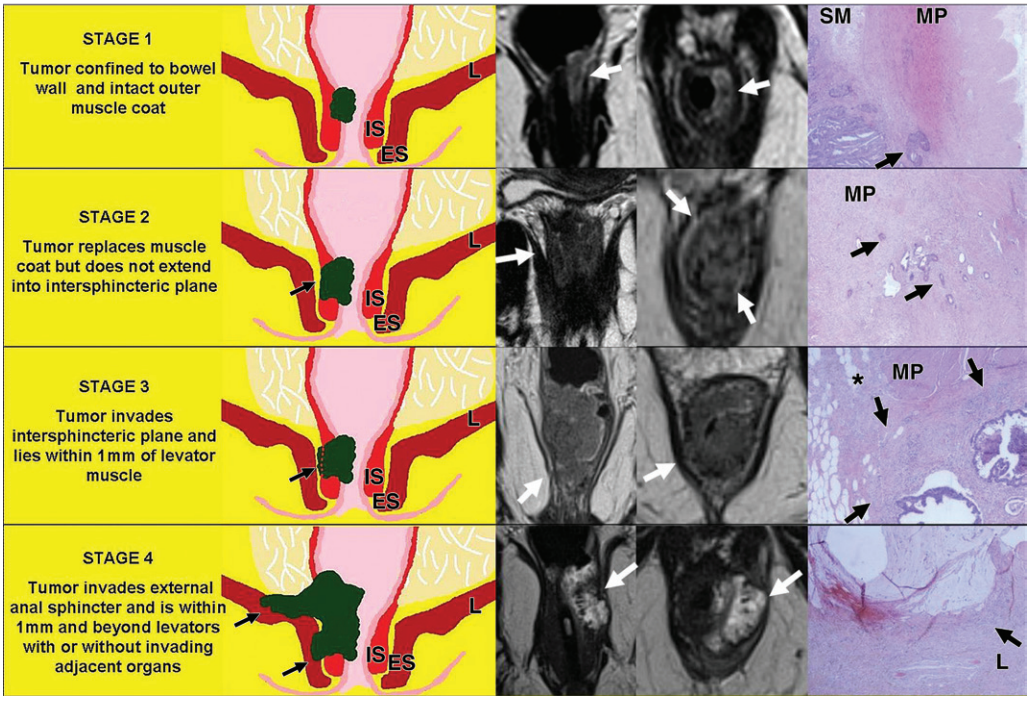


Figure 7: Schematic of high-spatial-resolution coronal and axial short-axis T2-weighted images with pathologic correlation (×4 magnification, hematoxylin-eosin stain) for each stage according to the low rectal cancer staging by Shihab et al (28). *ES* = external sphincter, *IS* = internal sphincter, *L* = levator muscle, *MP* = muscularis propria, *SM* = submucosa, * = intersphincteric space. Arrows indicate tumor.

plex to propose which patients need to receive CRT before surgery. For MR imaging of early stage tumors with safe radial and distal margins, primary surgery and avoidance of irradiating the sphincter results in better postoperative sphincter function and lower rates of anastomotic breakdown (23). Preoperative CRT in locally advanced low rectal tumors has been shown to increase the sphincter preservation rate and disease-free survival (24–26). This allows a tumor that would have previously required an abdominoperineal excision to be excised by means of ultralow resection and coloanal anastomosis (27).

Recently, Shihab et al (28,29) proposed a specific T staging for low rectal tumors to better define the tumor-free margin. This staging is based on the coronal and axial T2-weighted images and is summarized in Figure 7. It allows surgeons to choose the excision plane. Indeed, for low rectal tumors, three different major surgeries can be performed depending on the tumor staging (Fig 8).

Low anterior resection consists of an en bloc resection of the rectum and of the mesorectum (ie, TME) to the level of the pelvic floor with a negative and radial resection margin (black lines on Fig 8). This technique can be performed for low rectal tumors without sphincter complex invasion and such patients can successfully avoid the sphincter morbidity associated with preoperative radiation therapy.

Low anterior resection with intersphincteric resection (green lines, Fig 8): If the tumor extends to the internal sphincter, low anterior resection can be continued into the intersphincteric plane. To produce uninvolved margins, the intersphincteric plane must be tumor-free and the tumor should not extend to within 1 mm of the outer border of the internal sphincter (stage 1 on MR images [Fig 7]).

Figure 8

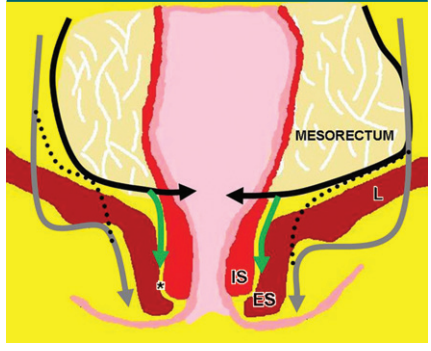


Figure 8: Schematic of the different surgical techniques that can be performed for low rectal tumors. *ES* = external sphincter, *IS* = internal sphincter, *L* = levator. * = intersphincteric space. Black lines = low anterior resection consisting of an en bloc resection of the rectum and mesorectum. Green lines = low anterior resection with intersphincteric resection. Dashed line = conventional abdominoperineal resection. Gray line = extralevator abdominoperineal resection removing more tissue surrounding the tumor with the advantage of less risk of positive margin.

Extralevator abdominoperineal resection (APR): The oncologic outcome of standard APR (dashed line, Fig 8) is poor due to the high rate of positive margins (22). Recently, an extralevator APR (gray line, Fig 8) approach has been developed by Holm et al (30). The main difference between the extralevator APR and conventional APR surgical approaches is that the mesorectum is not dissected off the levator muscle in extralevator APR (Fig 8); the entire levator muscle is resected en bloc with the lower rectum and anal canal. This creates a cylindrical specimen with more tissue surrounding the tumor with the benefit of a low rate of positive resection margins, leading to a low rate of local recurrence (30–32). This procedure is performed when the tumor extends into the full thickness of muscularis propria, into or beyond the levator muscles, and/or tumor involves the intersphincteric space (stage 2, 3, or 4 on MR images [Fig 7]).

The following are diagnostic clues at the workstation for staging low-lying tumors:

1. High-spatial-resolution T2-weighted fast spin-echo coronal imaging must be added to optimally depict the tumor relationship with the levator and puborectal muscles, sphincter complex, and intersphincteric plane.

2. On coronal T2-weighted images, the beginning of the puborectalis sling marks the start of the narrowest part of the mesorectum; below lies the anal canal (comprised of mucosa, submucosa, internal sphincter, intersphincteric plane [1–2 mm], and external sphincter) (Fig 3). The first question to answer in low-lying tumors is where the lower edge of the tumor is located in relation to the puborectalis sling. If the tumor is located above the puborectalis sling, sphincter involvement can be easily excluded.

3. When the tumor extends below the puborectalis sling: Three areas have to be evaluated and reported (Fig 7): *(a)* muscularis propria—Does the tumor invade partially or the full thickness of the muscularis propria (stage 1 vs 2)? *(b)* Is there an extension into the intersphincteric plane (stage 3)? *(c)* Is there an extension into the external sphincter (stage 4)?

Figure 9

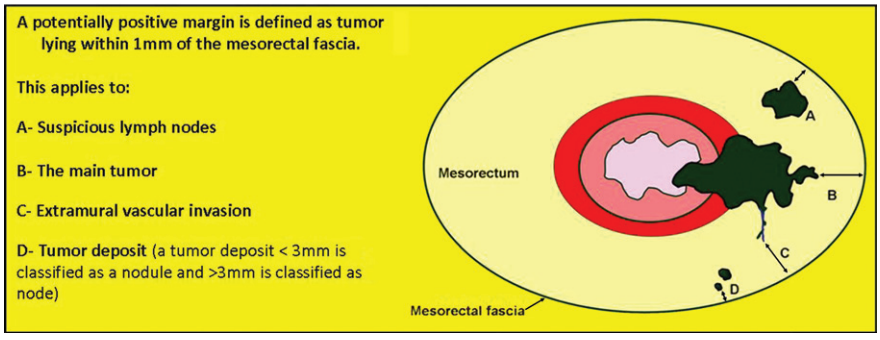


Figure 9: Schematic representation of positive resection margin.

4. Levator, puborectalis muscles, or external sphincter involvement are considered stage 4.

N: Nodal Staging

Exact nodal staging is important because the number of metastatic nodes has been shown to affect the prognosis. Determining the presence of nodal involvement on MR images has traditionally relied on size assessment. However, there is considerable overlap in size between normal, reactive, and metastatic lymph nodes. Moreover, micrometastasis in normal-sized lymph nodes is common. Therefore, size is not advocated as a reliable way of assessing whether lymph nodes harbor tumor. Criteria based on the shape, border, and signal intensity characteristics have been shown to be more reliable (10,33,34). By using these criteria, MR imaging can be used to determine lymph node involvement with an accuracy of 85% compared with histopathologic evaluation as a standard of reference. However, a negative MR imaging finding cannot exclude lymph node metastases, because imaging techniques cannot be expected to help identify micrometastasis within lymph nodes. Some promise in distinguishing between N0 and N1/2 disease has been shown by using MR imaging with lymph node–specific contrast enhancement (35); however, ultrasmall superparamagnetic iron oxide contrast material has not been approved by the U.S. Food and Drug Administration or the European Medicines Agency and will not be available for clinical use in the coming years.

The following are diagnostic clues at the workstation for nodal staging:

1. Uniform nodes smaller than 10 mm with homogeneous signal intensity are not suspicious.

2.Nodes with irregular borders, mixed signal intensity, or both are considered to be suspicious.

3. Presence of one to three suspicious nodes is stage N1 and presence of four or more is stage N2.

4. Any lymph node lying within 1 mm of the CRM must be reported because it is highly suspicious of CRM involvement.

5. Recording the location and size of any suspicious pelvic sidewall lymph nodes is critical (10). This will inform the radiation therapy team to change and adjust the radiation therapy field. Secondly, the surgeon will need to perform an extended lymph node resection with additional removal of the internal iliac nodes. This lymph node group is not removed when a regular TME is performed.

C: CRM

The mesorectal fascia is seen as a fine low-signal-intensity layer enveloping the perirectal fat and rectum and represents the surgical excision plane in TME anterior resections: On MR images, it is the potential CRM for patients undergoing TME surgery. CRM involvement is an important independent prognostic factor for local recurrence and poor survival (36–38). Figures 9 and 10 summarize the different patterns of positive margins on MR images.

The following are diagnostic clues at the workstation for a positive CRM:

Figure 10

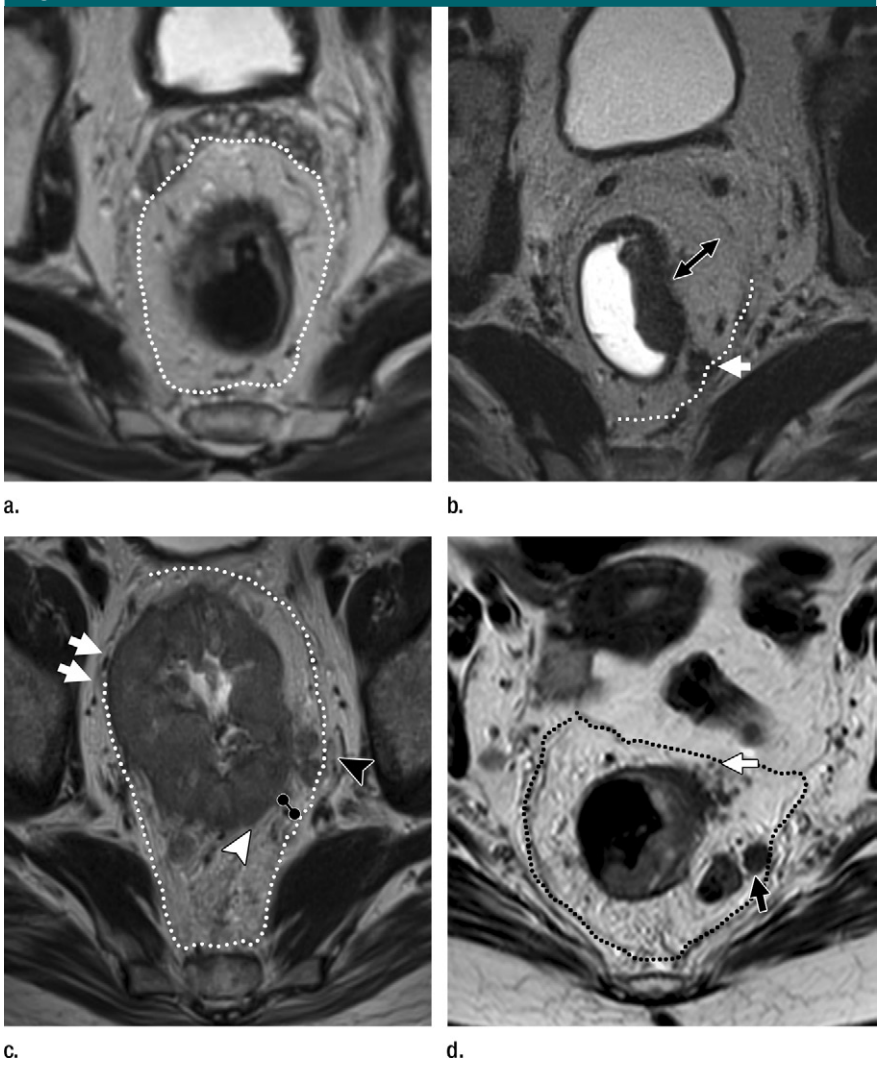


Figure 10: Axial T2-weighted images in different patients reporting the distance to the CRM and involvement of CRM. **(a)** Dashed line outlines the mesorectal fascia, which is the CRM in a T3a tumor with predicted clear CRM. **(b)** T3a tumor far away from the mesorectal fascia (black arrow). However, suspicious lymph node on the mesorectal fascia (white arrow) raises the possibility of potential CRM involvement (CRM = 0 mm). **(c)** T3d tumor confined within muscularis propria where the tumor is abutting the mesorectal fascia (arrows; at this level the tumor is T2). Invasive border appears to be posterolaterally on left (white arrowhead). The CRM regarding the tumor is evaluated at 5 mm. However, there are two mixed signal intensity lymph nodes (black arrowhead) abutting the mesorectal which leads to a CRM of 0 mm. **(d)** T3c tumor with EMVI bordering the peritoneum (white arrow) and irregular, heterogeneous signal intensity lymph nodes–there is tumor extension through the lymph node capsule, which is abutting the mesorectal fascia (black arrow) (predicted CRM = 0 mm).

1. A positive margin is defined as tumor lying within 1 mm of the mesorectal fascia.

2. Positive margins can be due to tumor deposits, main tumor extension, extramural vascular invasion (EMVI), or suspicious lymph nodes.

3. Anteriorly the mesorectal fat can be thin, and the rectum can be close to the CRM. In cases in which the rectum abuts the mesorectal fascia anteriorly, the tumor must be at least a stage T3 before discussing CRM involvement, as this is not relevant in T1 or T2 tumors.

E: Extramural Vascular Invasion

EMVI is reported to occur in up to half the cases of colorectal cancer (39) and is an independent risk factor for local and distant recurrence and poorer overall survival (39–41). It is defined as the presence of malignant cells within blood vessels located beyond the muscularis propria in the mesorectal fat. MR imaging is the only imaging modality that has been shown to consistently demonstrate EMVI in rectal cancer (42) (Figs 11, 12). Recently, the severity of MR imaging–depicted EMVI has been found to be correlated with disease-free survival (40).

The following are diagnostic clues at the workstation for EMVI:

1. By definition, EMVI must be associated with tumors that are at least category T3. A stage T1 or T2 has no potential for invading extramural vessels.

2. Whenever the tumor is seen to lie close to a vessel, the radiologist should consider the possibility of EMVI.

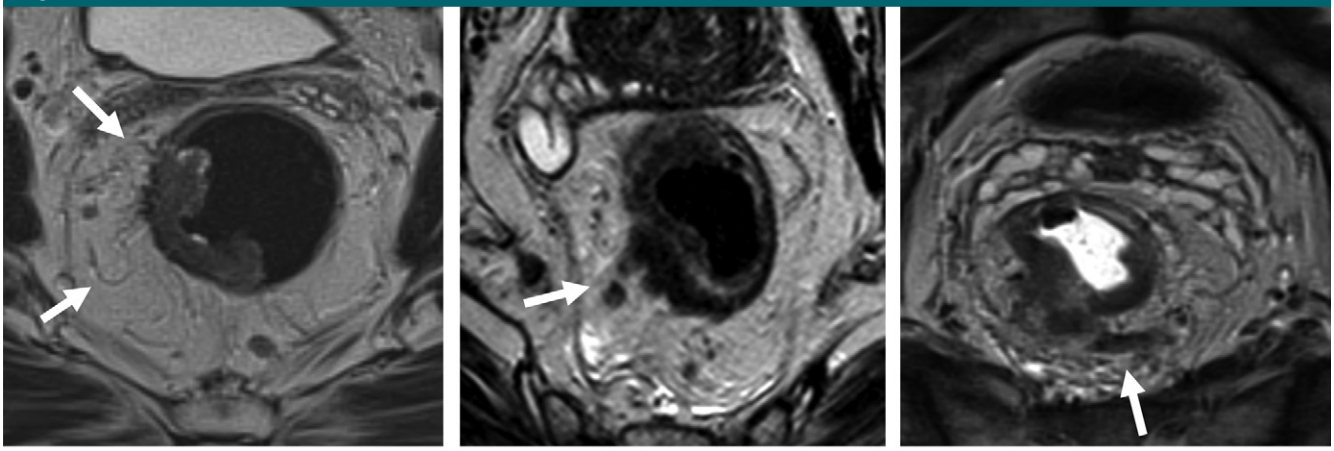
3. Signs suggestive for EMVI are *(a)* presence of tumor signal intensity within a vascular structure, *(b)* expanded vessels, and *(c)* tumoral expansion through and beyond the vessel wall, disrupting the vessel border.

4. Finally, if EMVI is present, considerations of whether the involved veins threaten the mesorectal fascia (ie, whether they are within 1 mm of the fascia) have to be made.

MR Image Interpretation: Mnemonic "DISTANCE" after CRT

Locally advanced rectal cancer has a poor prognosis because of the high frequency of metastasis and local recurrence. The benefits of downstaging and downsizing with neoadjuvant CRT include improvement in resectability, sphincter preservation, decreased rates of local recurrence, and overall survival (43,44). In several studies, CRT has resulted in 10%–20% complete tumor response rate (43,44). Indeed, changes in the original treatment plan after a good response are not uncommon. For example, a patient whose tumor invades the anal sphincter or a surrounding organ could ulti-

Figure 12



a. b. c.

Figure 12: MR imaging EMVI panel. **(a)** Minimal extramural stranding, with some normal vessels adjacent to the tumor (arrows), but no tumor signal intensity within the vessel: no evidence of EMVI (see Fig 11, *A*). **(b, c)** Intermediate signal intensity within the vessels. The caliber of the vessel is enlarged (arrow), which is highly suspicious for EMVI (see Fig 11, *B*).

mately benefit from sphincter- or organ-sparing surgery in case of a good initial response. Imaging after CRT is critical to propose "tailored therapies" that are patient centered (45). We use the same mnemonic and diagnostic clues to interpret rectal MR images after CRT, with some adjustment. Figure 13 summarizes the main indications for CRT.

DIS: Distance

After CRT with a good response, the tumor may not be visible on sagittal T2-weighted images, and planning the high-spatial-resolution axial T2-weighted acquisitions perpendicular to the tumor can be challenging. The previous examination and high-spatial-resolution T2-weighted images along the entire length of the rectum may be needed. Furthermore, tumor height also has to be reassessed before surgery since reduction of the craniocaudal length will affect the choice of operation.

T: T Staging

T downstaging, and more recently, tumor volume reduction and MR imaging tumor regression grade have been adopted to evaluate tumor response after CRT.

Morphologic criteria.—T downstaging: The reported overall accuracy of MR imaging in predicting the stage of nonirradiated rectal cancer is approximately 85%, but this rate falls to 50% after treatment (46,47). The difficulty lies in whether tumor is still present among posttherapeutic changes. Most tumors develop fibrosis, leading to a reduction on T2-weighted images and a decrease in tumor size. The interface between the tumor and the mesorectal fat shows frequent changes (Figs 14, 15). The main difficulty is to assess

Figure 11

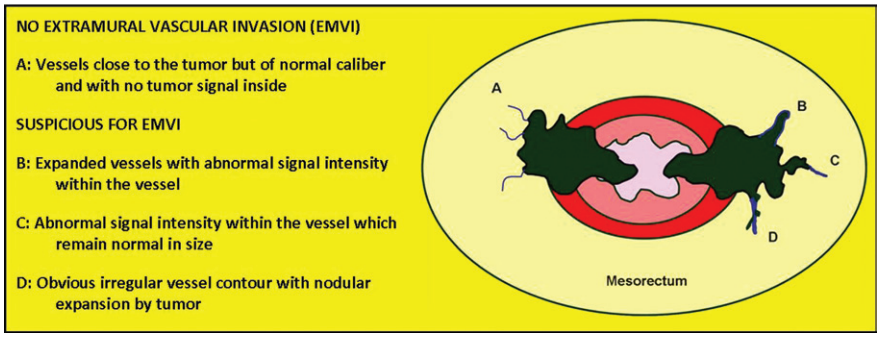


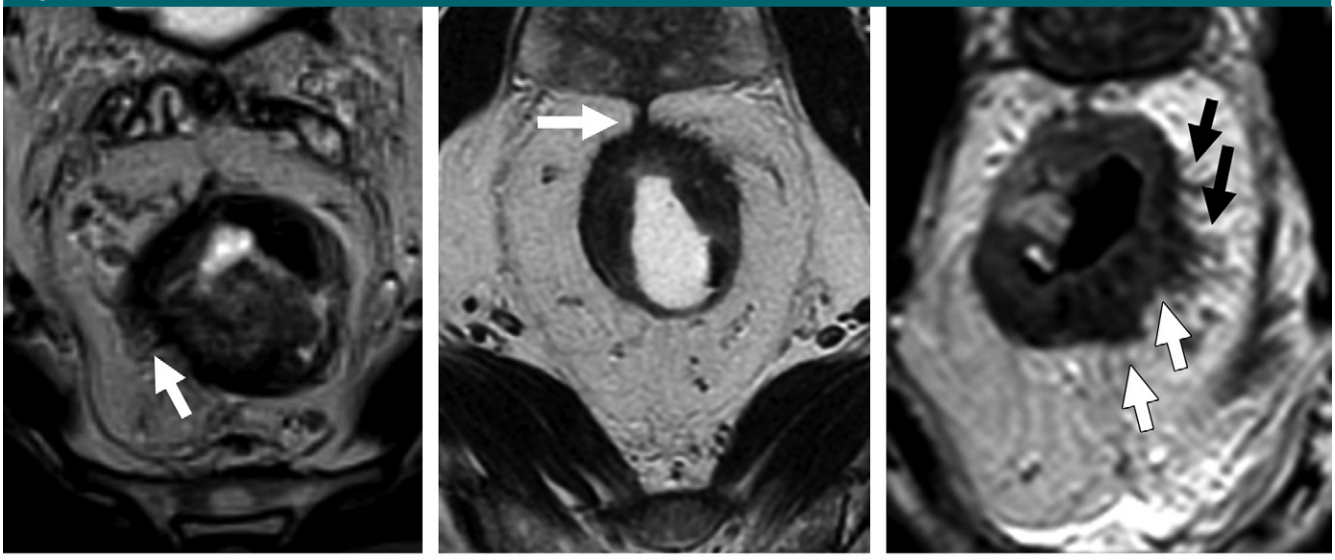
Figure 11: Schematic representation of EMVI.

Figure 13

Main Indications of CRT based on Risk of Pelvic Recurrence
Locally advanced rectal tumor T3 with >5 mm of extramural spread
EMVI
Tumor within 1 mm of the mesorectal fascia
Threatened or involved anal sphincter (low rectal staging classification)
Nodal involvement (if TME surgery is not performed)

Figure 13: List of the main indications for CRT before surgery in rectal cancer.

Figure 15



a. b. c.

Figure 15: Short-axis axial T2-weighted images show **(a)** multiple, thin, hypointense linear bands in the mesorectum corresponding to subtle fibrotic scaring (arrow), **(b)** single, thin, hypointense scar extending to the mesorectal fascia corresponding to a fibrotic reaction (arrow), and **(c)** a desmoplastic reaction, as seen by the fine low-signal-intensity strands (black arrows) and tumor which appears to be of intermediate signal intensity and more nodular (white arrows).

Figure 14

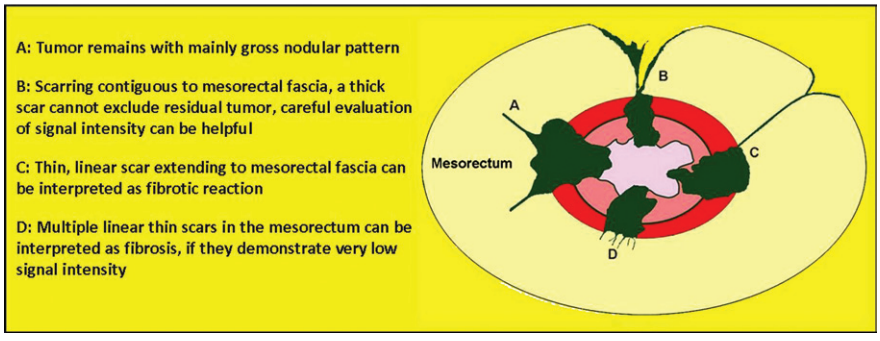


Figure 14: Schematic representation of post-CRT change.

whether the low-signal-intensity areas represents fibrotic scar or residual tumor. Recent studies have demonstrated the added value of DW MR imaging to differentiate viable tumor from fibrosis (48,49) and thus allows prediction of complete response (50). Areas of fibrosis typically have a low cellular density, which results in low signal intensity on high-*b*-value DW images. In contradistinction, residual tumor areas have a relatively high cellular density and show high signal intensity on DW images that stands out against the low signal intensity of the surrounding tissue and fibrosis (50,51). As such, small areas of residual tumor are better depicted on DW images. A recent study showed that an increased apparent diffusion coefficient in patients during and after CRT could be used to predict an early pathologic response to CRT (52). Nevertheless, DW image interpretation can be difficult in case of mucinous adenocarcinoma or colloidal posttherapeutic changes. Some treated tumors develop a "colloid" response, with mucin production that results in very high signal intensity on T2-weighted images and DW images, with no apparent diffusion coefficient restriction (T2 shine-through effect). Consequently, small residual tumor among the colloidal changes cannot be detected. In addition, distortion due to imaging artifacts is not infrequent with DW imaging, particularly around air-tissue interfaces, further complicating interpretation.

In addition to T downstaging, an MR imaging tumor regression grade (53) has been recently proposed derived from histopathologic grading (54) and seems to be a strong prognostic indicator for tumor recurrence and survival outcomes. This new grading is based on the assumption that fibrosis results in very low SI compared with tumor on T2-weighted images, and mucin in very high signal intensity (Fig 16).

Size criteria.—Recently, volume downsizing was combined with MR morphologic changes (55–59) and had been reported to correlate well with pathologic tumor response in terms of downstaging and tumor regression grade

(55,60). Tumor volumes are calculated on axial high-spatial-resolution T2-weighted MR images by manually tracing the lesion border and then summing all of the cross-sectional volumes by using a dedicated software package. In our experience, a tumor volume reduction of 70% or more after CRT was associated with a good tumor regression grade at pathologic examination (59,61) and higher disease-free survival (61). Furthermore, a significant association with pathologic complete response was reported for patients with a volume reduction rate higher than 75% (57). Interestingly, early results regarding DW MR imaging and MR volumetry for predicting tumor response were contradictory. For example, Kim et al (56) found that early tumor volume reduction rate may be a better indicator than DW imaging for predicting CRT treatment outcome, while Lambrecht et al (52) found higher accuracy with DW imaging. Maybe an interesting tool for response assessment could be found by combining functional (DW) and morphologic (volumetry) imaging as recently described by Curvo-Semedo et al (58). In their study, post-CRT DW MR imaging volumetry was highly accurate in the prediction of complete response compared with use of T2-weighted images. Indeed, on morphologic post-CRT T2-weighted images, volume can be difficult to evaluate owing to the necessity to define which of the fibrotic areas are still suspicious, and therefore should be included in the volume measurements. On DW images, the delineation of residual tumor is typically more evident.

In our experience, we used both qualitative (tumor regression grade) and volumetry for assessing tumor response.

A: Anal Complex—Sphincters and Puborectal Muscles

Details for the anal complex are the same as for pre-CRT MR imaging, described above.

N: Nodal Staging

After CRT, lymph node downstaging also occurs, with a reported decrease in the rate of tumors with malignant lymph nodes found at histopathologic evaluation, from 40% before CRT to 25% after completion of CRT (44,62). As is the case for pre-CRT MR imaging nodal evaluation, lymph node staging for post-CRT MR imaging also has moderate accuracy (63–65). It is difficult to differentiate a metastatic lymph node from a lymph node with irradiation changes on post-CRT MR images by using morphologic criteria. After CRT, a spiculated lymph node border is often seen even in cases of negative nodes owing to fibrosis. Ultrasmall superparamagnetic iron oxide would appear an interesting agent with which to assess lymph nodes involvement after CRT, but this agent is not available in the United States or in Europe (35,65,66).

C: CRM

MR imaging has an accuracy of 66% in the prediction of CRM involvement during restaging of irradiated rectal cancers (67). A fibrotic scar attached to the mesorectal fascia (Fig 14) can be difficult to differentiate from remaining tumor tissue; it is critical for the surgical approach to detail the post-CRT tumor margin. The MERCURY study group has shown the strong negative predictive value (98%) of MR imaging for radial margin involvement (68). The positive predictive value has shown that there is a tendency to overstage, but despite this, the identification at MR imaging of persistent potential CRM involvement is associated with significantly higher local recurrence rates (53). Therefore, continued involvement of the CRM after CRT is important because for patients with resection margins that continue to be potentially involved, they could be offered either further neoadjuvant treatment or undergo a more extensive radical resection. On the other hand, a patient whose tumor is beyond the CRM on baseline images may have undergone regression to within the CRM after CRT, enabling him or her to be a candidate for TME excision. As before CRT, it is not only tumor that can threaten the CRM, but also lymph nodes, tumor deposits, or EMVI.

E: Extramural Vascular Invasion

Details for EMVI are the same as for pre-CRT MR imaging, described above.

Figure 17 summarizes the mnemonic device.

Some additional materials can be found online to guide readers. Figures E1–E3 (online) show examples of tumors before and after CRT evaluated by using the mnemonic device. Movies 1–3 (online) outline the main teaching points for rectal cancer evaluation at MR imaging.

Advances have been made in the treatment of rectal cancer, which have considerably improved patient prognosis. We are now in an era in which treatment is tailored according to individual risk. MR imaging is currently the only imaging modality that allows an accurate evaluation of the patient's tu-

Figure 16

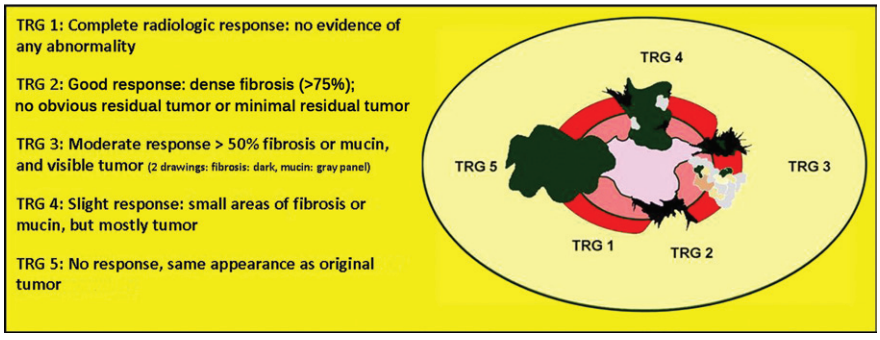


Figure 16: Schematic representation of MR imaging tumor regression grade *(TRG)*.

Figure 17

DIS: Distance from the inferior part of the tumor to the transitional skin
- Low third (<5 cm)
- Middle third (5–10 cm)
- Upper third (>10 cm)

T: T staging—Extramural spread must be recorded, as well as peritoneal reflection involvement
- T1: Tumor invades submucosa
- T2: Tumor invades but does not penetrate muscularis propria
- T3: Tumor invades subserosa through muscularis propria
  - T3a: Tumor extends < 1 mm beyond muscularis propria
  - T3b: Tumor extends ≥ 1–5 mm beyond muscularis propria
  - T3c: Tumor extends > 5–15 mm beyond muscularis propria
  - T3d: Tumor extends > 15 mm beyond muscularis propria
- T4: Tumor peritoneal reflection (T4a) or other organs (T4b)

A: Anal complex for low-lying tumor with specific classification
- Stage 1: tumor invading partial thickness of muscularis propria
- Stage 2: tumor invading full thickness of muscularis propria
- Stage 3: tumor invading the intersphincteric plane
- Stage 4: tumor less than 1 mm or beyond the puborectal muscle

N: N staging, assessed on border definition and signal criteria
- N0: No metastatic lymph nodes
- N1: Metastasis in 1–3 perirectal nodes
- N2: Metastasis in 4 or more perirectal nodes
- Pelvic side wall lymph nodes must be recorded for radiation therapy field and surgery adjustment

C: CRM (circumferential resection margin)
- A positive margin is defined as: tumor, lymph nodes, EMVI, or tumoral deposits lying within 1 mm (<1 mm) of the mesorectal fascia

E: Extramural vascular invasion

Figure 17: Summary of the "DISTANCE" mnemonic device.

mor prognosis. Radiologists need to be aware of what information is relevant for the clinicians. Standardized imaging techniques and reports could promote consistent accuracy and help treatment decisions.

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