

MR Imaging for Preoperative Evaluation of Primary Rectal Cancer: Practical Considerations¹

TEACHING POINTS

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High-resolution magnetic resonance (MR) imaging plays a pivotal role in the pretreatment assessment of primary rectal cancer. The success of this technique depends on obtaining good-quality high-resolution T2-weighted images of the primary tumor; the mesorectal fascia, peritoneal reflection, and other pelvic viscera; and superior rectal and pelvic sidewall lymph nodes. Although orthogonal axial high-resolution T2-weighted MR images are the cornerstone for the staging of primary rectal cancer, high-resolution sagittal and coronal images provide additional value, particularly in tumors that arise in a redundant tortuous rectum. Coronal high-resolution T2-weighted MR images also improve the assessment of nodal morphology, particularly for superior rectal and pelvic sidewall nodes, and of the relationship between advanced-stage tumors and adjacent pelvic structures. Rectal gel should be used in MR imaging examinations conducted for the staging of polypoid tumors, previously treated lesions, and small rectal tumors. However, it should not be used in examinations performed to stage large or low rectal tumors. Diffusion-weighted imaging is useful for identifying nodes and, occasionally, the primary tumor when the tumor is difficult to visualize with other sequences. Three-dimensional T2-weighted imaging provides multiplanar capability with a superior signal-to-noise ratio compared with two-dimensional T2-weighted imaging.

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Abbreviations: ADC = apparent diffusion coefficient, CRM = circumferential resection margin, FOV = field of view, FSE = fast spin-echo, SNR = signal-to-noise ratio, 3D = three-dimensional, TME = total mesorectal excision, 2D = two-dimensional

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Introduction

High-resolution T2-weighted imaging is the key sequence in the magnetic resonance (MR) imaging evaluation of primary rectal cancer. This sequence generally consists of thin-section (3-mm) axial images obtained orthogonal to the tumor plane, with an in-plane resolution of 0.5–0.8 mm. In experienced hands, this technique allows differentiation between rectal tumors confined within the rectal wall (stage T2 tumors) and those that extend beyond the muscularis propria (stage T3 tumors) (1). Most important, the depth of invasion outside the muscularis propria can be assessed with a high degree of accuracy (2). In addition, high-resolution T2-weighted images allow the morphologic assessment of pelvic nodes, thereby improving accuracy in the characterization of nodes as benign or malignant, since size criteria have proved to be of limited value (3).

In this article, we review the indications for and limitations of MR imaging in the preoperative evaluation of primary rectal cancer. In addition, we address commonly encountered difficulties in the effort to obtain good-quality high-resolution MR images of rectal tumors and offer possible solutions. We also discuss the utility of newer imaging sequences (eg, three-dimensional [3D] T2-weighted imaging and diffusion-weighted imaging) in this context.

Background

In the setting of primary rectal cancer, MR imaging is used to assist in staging, in identifying patients who may benefit from preoperative chemotherapy–radiation therapy, and in surgical planning.

Currently, surgical resection with stage-appropriate neoadjuvant combined-modality therapy is the mainstay in the treatment of rectal cancer. In the past decade, the increasingly widespread adoption of total mesorectal excision (TME) has resulted in a dramatic decline in the prevalence of local recurrence from 38% to less than 10% (4). TME is a surgical technique that entails en bloc resection of the primary tumor and the mesorectum by means of dissection along the mesorectal fascial plane or the circumferential resection margin (CRM) (4). Even with TME, however, the presence of a tumor or malignant node within 1 mm of the CRM remains an important pre-

disposing factor for local recurrence (5). Consequently, reliable preoperative imaging evaluation is vital to surgical planning.

The timing of radiation therapy in the treatment of primary rectal cancer has been controversial, but randomized trials have shown that combined preoperative radiation therapy–TME reduces the prevalence of local recurrence from 8% to 2% and is superior to postoperative radiation therapy alone (6,7). These studies also revealed that radiation therapy yields little survival benefit and results in significant morbidity when used to treat stage T1–T2 or favorable-risk early stage T3 tumors (<5 mm invasion outside the muscularis propria) in contrast to more advanced stage T3 tumors (>5 mm invasion outside the muscularis propria) (7).

The evolution of surgical techniques and the shift to neoadjuvant chemotherapy–radiation therapy, along with the prognostic heterogeneity of stage T3 tumors, necessitate accurate preoperative staging—primarily in terms of tumor (T) and nodal (N) staging, depth of tumor invasion outside the muscularis propria (early versus advanced stage T3 tumors), and the relationship of the tumor to the potential CRM. The accurate assessment of these factors allows the triage of patients to up-front surgical resection or short- or long-course preoperative radiation therapy or chemotherapy–radiation therapy with appropriate modification of the CRM. Recent studies have shown that high-resolution MR imaging is a reliable and reproducible technique with high specificity (92%) for predicting a negative CRM, the relationship of the tumor to the CRM, and the depth of tumor invasion outside the muscularis propria (2,8,9).

However, the assessment of nodal involvement remains a confounding factor. Patients with malignant adenopathy should receive chemotherapy–radiation therapy; however, cross-sectional imaging relies on size as a criterion for nodal involvement, which has significant limitations. High-resolution MR imaging allows the assessment of nodal morphology, which significantly improves specificity in the assessment of nodal involvement. One limitation is the significant learning curve, as shown by the difficulty in reproducing the high sensitivity reported by Brown et al (3,10).

The objectives of MR imaging in primary rectal cancer reflect the treatment decision-making process and can be categorized as assessment of the primary tumor and assessment of nodal involvement.

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Table 1
TNM Guidelines for the Staging of Rectal Cancer

Descriptor	Definition
Tumor	
Tx	Determination of tumor extent is not possible because of incomplete information
Tis	Tumor in situ involves only the mucosa and has not grown beyond the muscularis mucosa (inner muscle layer)
T1	Tumor grows through the muscularis mucosa and extends into the submucosa
T2	Tumor grows through the submucosa and extends into the muscularis propria
T3	Tumor grows through the muscularis propria and into the mesorectum
T3a	Tumor extends <5 mm beyond the muscularis propria*
T3b	Tumor extends 5–10 mm beyond the muscularis propria*
T3c	Tumor extends >10 mm beyond the muscularis propria*
T4a	Tumor penetrates the visceral peritoneum
T4b	Tumor directly invades or is adherent to other organs or structures
Node	
Nx	Nodal staging is not possible because of incomplete information
N0	No cancer in regional lymph nodes
N1a	Tumor in one regional lymph node
N1b	Tumor in two or three regional nodes
N1c	Tumor deposits in the subserosa, mesentery, or nonperitonealized pericolic or perirectal tissues without regional nodal metastasis
N2a	Tumor in four to six regional nodes
N2b	Tumor in seven or more regional nodes
Metastases	
M0	No distant spread
M1a	Tumor is confined to one distant organ or site (eg, liver, lung, ovary, nonregional node)
M1b	Tumor spread to more than one organ or site or the peritoneum
Stage	
0	Tis, N0, M0
I	T1–T2, N0, M0
IIA	T3, N0, M0
IIB	T4a, N0, M0
IIC	T4b, N0, M0
IIIA	T1–T2, N1, M0; T1, N2a, M0
IIIB	T3–T4a, N1, M0; T2–T3, N2a, M0; T1–T2, N2b, M0
IIIC	T4a, N2a, M0; T3–T4a, N2b, M0; T4b, N1–N2, M0
IVA	Any T, any N, M1a
IVB	Any T, any N, M1b

Note.—Adapted from the American Joint Committee on Cancer staging system (11).

*Adapted from the RSNA Radiology Reporting Templates (12).

Assessment of the Primary Tumor

MR imaging of primary rectal tumors can be used to assess the tumor in terms of (*a*) stage; (*b*) depth of invasion outside the muscularis propria; and (*c*) relationship to the mesorectal fascia, anal sphincter, and pelvic sidewall.

The American Joint Committee on Cancer (tumor-node-metastasis [TNM]) guidelines have been used to develop MR imaging criteria for the staging of primary rectal tumors (Table 1) (11).

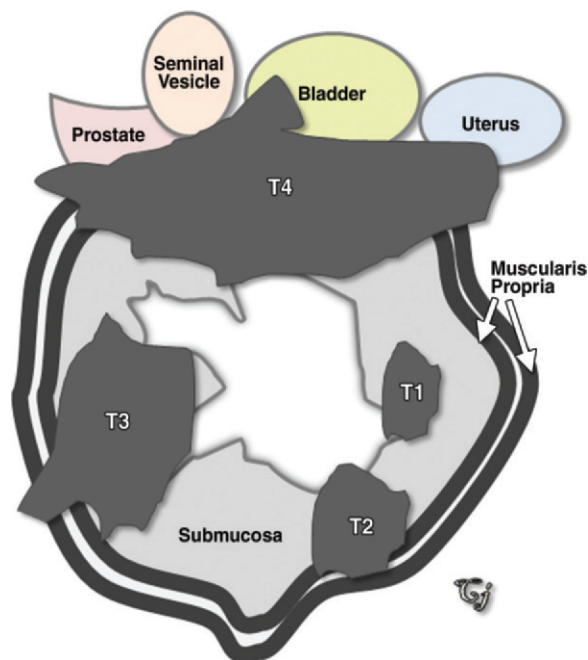


Figure 1. Drawing illustrates tumor staging in rectal cancer. Stage T1 tumors are confined to the submucosa; stage T2 tumors invade the muscularis propria (arrows), which consists of a circular inner muscle layer and a longitudinal outer layer; stage T3 tumors extend beyond the muscularis propria; and stage T4 tumors involve adjacent organs or the peritoneum.

These criteria are based on the definition of rectal wall anatomy on high-resolution T2-weighted images and the relationship of the tumor to the submucosa and muscularis propria (Fig 1). On T2-weighted images, stage T1 tumors are confined to the submucosa, which manifests as a hyperintense layer; stage T2 tumors extend into, but not beyond, the muscularis propria, which manifests as a hypointense layer (Fig 2); and stage T3 tumors extend beyond the muscularis propria into the mesorectal fat (Fig 3).

Although some studies have reported a high accuracy for MR imaging in tumor staging, these results have not been widely reproduced. The accuracy of MR imaging in this context depends on the experience of the radiologist and is subject to significant inter- and intraobserver variability (1,9,13). Limitations include difficulty in differentiating fibrosis from tumor infiltration, which compromises the ability to distinguish early stage T3 tumors from stage T2 tumors (14). **It appears that, although MR imaging is accurate in advanced stage T3 tumors, considerable experience and good-quality images are required to assess the subtle findings that help distinguish early stage T3 tumors from stage T2 tumors.** In the sub-



Figure 2. T2 tumor. Orthogonal axial high-resolution T2-weighted MR image shows an ulcerated tumor (arrowhead) along the posterior rectal wall. The muscularis propria is seen as a thin hypointense line (white arrow). Along the posterior right lateral wall, tumor is seen to focally penetrate into the muscularis propria (black arrow) but not through it.

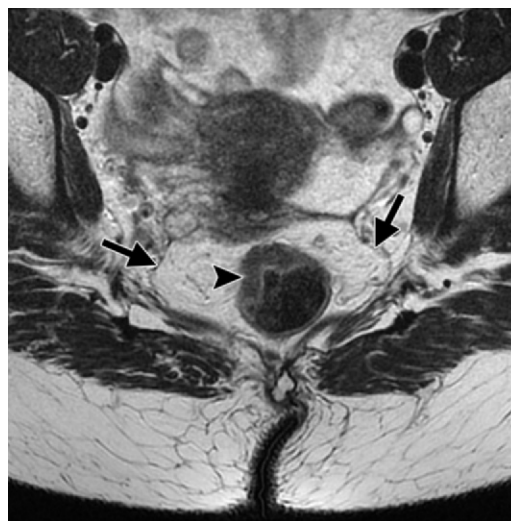
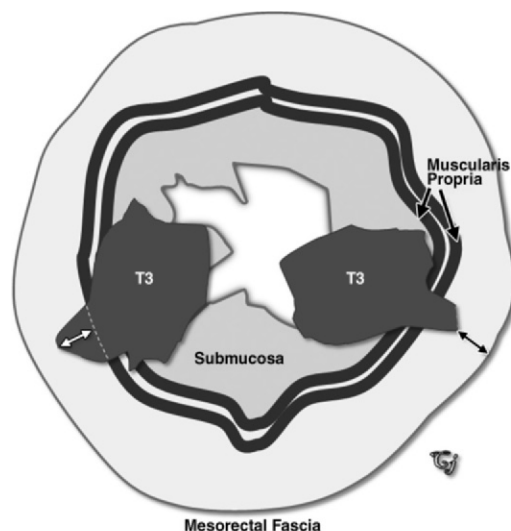
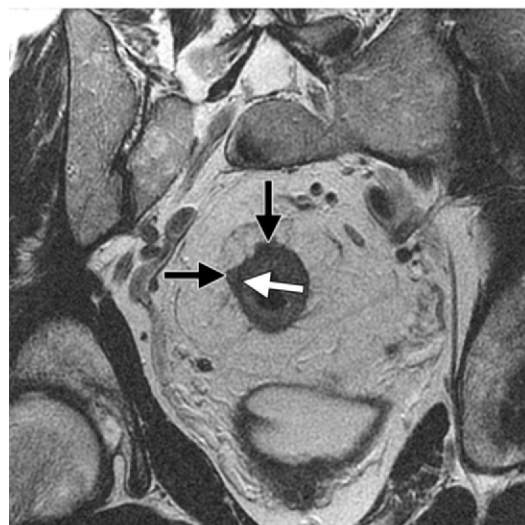


Figure 3. T3 tumor. Orthogonal axial high-resolution T2-weighted MR image shows an ulcerated lesion (arrowhead) along the anterior aspect of the rectum infiltrating through the muscularis propria into the mesorectal fat. The mesorectal fascia is seen as a thin hypointense line (arrows) surrounding the mesorectal fat.

group of superficial tumors, endoscopic ultrasonography (US) is reportedly a more accurate staging modality (13,14). Overall, however, the



4.



5a.



5b.

Figures 4, 5. (4) Drawing illustrates two stage T3 tumors in the rectal wall. White double-headed arrow = depth of invasion beyond the muscularis propria, black double-headed arrow = relationship of tumor to the mesorectal fascia. (5) Depth of invasion outside the muscularis propria. (a) Orthogonal high-resolution T2-weighted MR image shows tumor extension through the muscularis propria at multiple points (black arrows). The residual muscularis propria is seen as a subtle hypointense line (white arrow). The maximum depth of invasion outside the muscularis propria is approximately 5 mm. (b) Orthogonal high-resolution T2-weighted MR image obtained in a different patient shows significant tumor infiltration (black arrow) beyond the muscularis propria (white arrow). Arrowhead = mesorectal fascia.

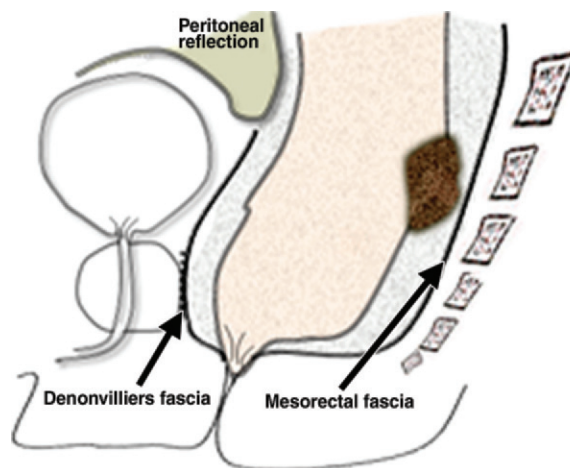
staging of superficial rectal tumors is challenging, with both MR imaging and US requiring considerable experience.

Depth of Tumor Invasion Outside the Muscularis Propria

Depth of tumor invasion outside the muscularis propria is not considered in TNM staging; however, it has substantial clinical significance. In Table 1, the American Joint Committee on Cancer criteria for the staging of rectal cancer have been modified to incorporate depth of invasion outside the muscularis propria. The definitions of stage T3a–T3c tumors have been taken from the standardized MR reporting criteria incorporated into the Radiological Society of North America's radiology reporting template for primary rectal cancer (12).

The majority (80%) of rectal tumors are stage T3 lesions that form a heterogeneous group, with 5-year survival rates varying based on the depth of tumor invasion outside the muscularis propria. The cancer-specific survival rate drops from 85% to 54%, independent of nodal involvement, when the depth of tumor invasion outside the muscularis propria exceeds 5 mm (15). This suggests that early stage T3 tumors (<5 mm invasion) and stage T2 tumors may be grouped together, separate from advanced stage T3 tumors, for prognostic and treatment purposes (Figs 4, 5). The Magnetic Resonance Imaging and Rectal Cancer European Equivalence Study (or MERCURY trial), a multi-institutional study evaluating the accuracy of high-resolution T2-weighted MR

Figure 6. Drawing of the pelvis (sagittal view) shows a tumor (brown) arising from the rectum (tan) and invading the mesorectal fat (gray). The mesorectal fascia runs along the anterior aspect of the sacrum. The presacral fascia is not defined as a separate layer, since it is frequently indistinguishable from the mesorectal fascia at imaging. Anteriorly in males, the mesorectal fascia forms the Denonvilliers fascia and superiorly fuses with the peritoneal reflection.



imaging in assessing depth of tumor invasion outside the muscularis propria, found this modality to be accurate and the results to be reproducible across institutions (2). The study found that the depth of tumor invasion outside the muscularis propria as measured at high-resolution MR imaging was within 0.5 mm of that measured at histopathologic examination (2).

Relationship of Tumor to Other Anatomic Structures

Mesorectal Fascia.—The mesorectal fascia, or visceral layer of the endopelvic fascia, encircles the rectum and the mesorectal fat, nodes, and lymphatic vessels to form a distinct anatomic unit. The mesorectal fascia runs along the anterior aspect of the sacrum, where it fuses with the presacral fascia, and then laterally on either side of the rectum, where it is easily identified on axial T2-weighted images as a thin hypointense line (Fig 3). Anteriorly in males, it forms a dense band of connective tissue posterior to the seminal vesicle and prostate gland called the Denonvilliers fascia (Fig 6). The relationship of the tumor to the mesorectal fascia (Figs 4, 7) is critical for surgical planning and, unlike tumor stage, can be reliably assessed at MR imaging with high accuracy and intra- and interobserver agreement. A distance greater than 1 mm between the tumor

and the CRM at histopathologic examination has been shown to correlate with a decrease in local recurrence (5). At our institution, we consider a measured distance of 1 mm or less on high-resolution T2-weighted images to be indicative of CRM involvement. It is critical to remember that this measured distance is the distance to the mesorectal fascia from either (a) the tumor margin, (b) a tumor deposit in the mesorectum, (c) tumor thrombus within a vessel, or (d) a malignant node. Endorectal US, although accurate in the staging of rectal tumors (particularly superficial tumors), is limited in the assessment of the relationship of a tumor to the mesorectal fascia because of its limited field of view (FOV) (10). This represents a substantial limitation with respect to presurgical planning.

Peritoneal Reflection.—The peritoneum reflects off the superior aspect of the urinary bladder and onto the anterior aspect of the rectum, forming the rectovesical pouch (Fig 6). On sagittal T2-weighted images, the peritoneum is seen as a hypointense linear structure (Fig 8a). On axial images, it has a V shape and attaches onto the anterior aspect of the rectum (Fig 8b). In our experience, the peritoneal reflection is best identified on sagittal or coronal high-resolution T2-weighted images. The relationship between tumor and the peritoneal reflection is important in staging, since rectal tumors with invasion through the peritoneal reflection are categorized as stage T4a lesions (Fig 8).

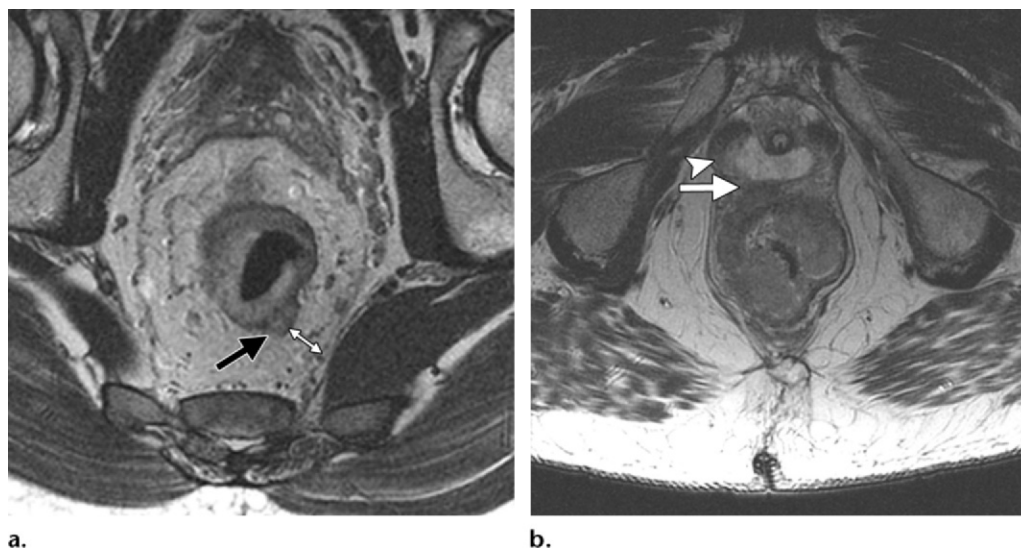


Figure 7. Relationship of tumor to the mesorectal fascia. **(a)** Orthogonal axial high-resolution T2-weighted MR image shows a tumor that infiltrates into the mesorectal fat (arrow) but does not involve the mesorectal fascia. Double-headed arrow = distance between leading edge of tumor and mesorectal fascia. **(b)** Orthogonal axial high-resolution T2-weighted MR image shows tumor infiltration (arrow) through the anterior rectal wall and into the mesorectal fat. The tumor abuts the mesorectal fascia posterior to the prostate gland (arrowhead).

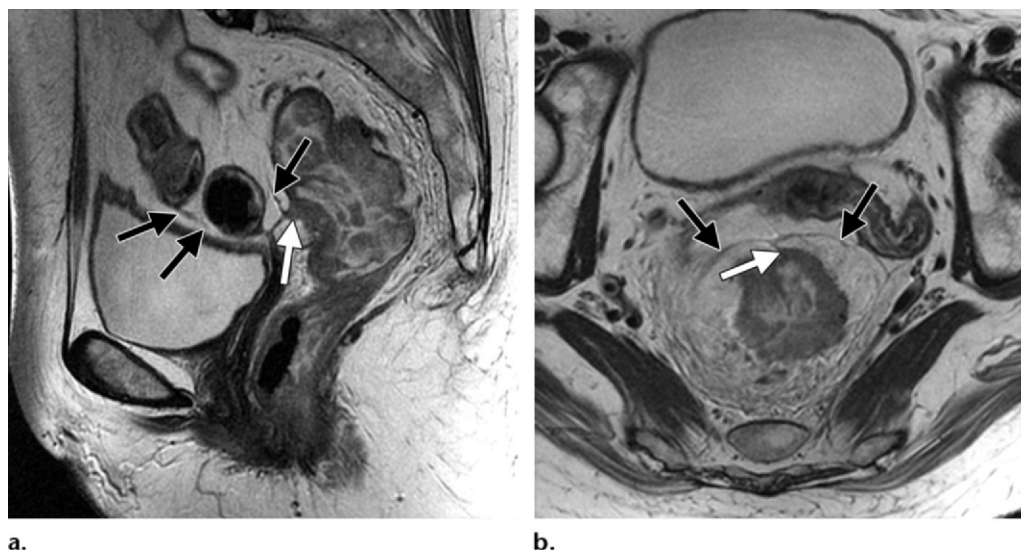


Figure 8. Relationship of tumor to the peritoneal reflection. **(a)** Sagittal high-resolution T2-weighted MR image shows the peritoneal reflection as a thin hypointense line (black arrows) along the superior aspect of the bladder reflecting onto the anterior aspect of the rectum. There is a high rectal tumor (white arrow) that extends through the muscularis propria to infiltrate the peritoneal reflection. **(b)** Orthogonal axial high-resolution T2-weighted MR image shows similar findings, with the peritoneal reflection manifesting as a thin hypointense line (black arrows) and the tumor infiltrating the muscularis propria circumferentially and the peritoneal reflection anteriorly (white arrow).

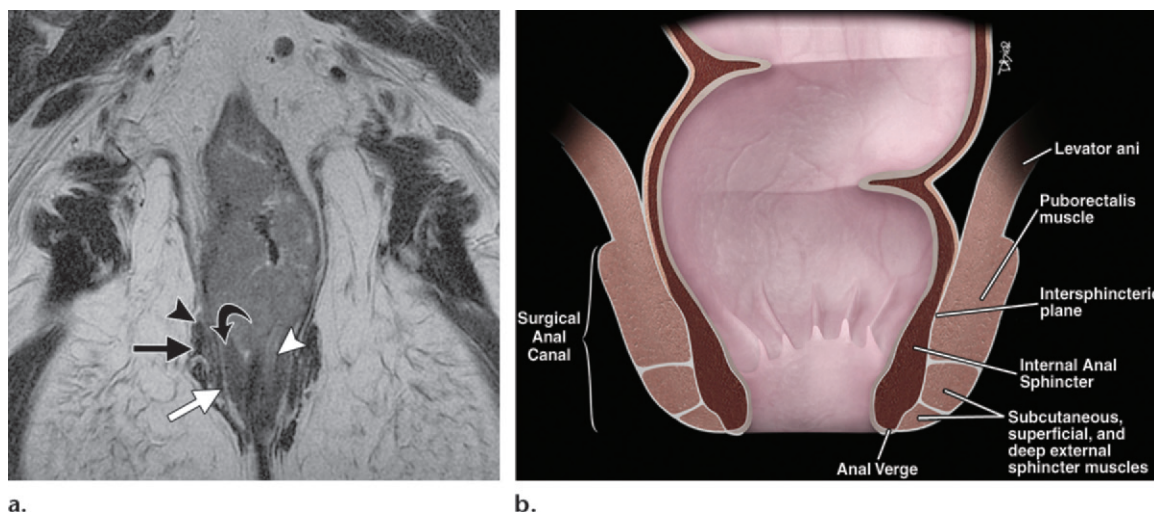


Figure 9. Relationship of tumor to the anal sphincter. **(a)** Coronal high-resolution T2-weighted MR image shows a low rectal tumor involving the left side of the internal anal sphincter (white arrowhead). The right side of the internal sphincter (curved black arrow) is separated from the puborectalis muscle (straight black arrow) by the thin, hyperintense intersphincteric plane (white arrow). The upper margin of the puborectalis muscle (black arrowhead) defines the upper border of the surgical anal canal. **(b)** Drawing shows the internal sphincter as thickening and continuation of the circular muscle layer of the rectum. The external sphincter complex is composed of the inferior portion of the levator ani muscle; the puborectalis muscle; and the deep, superficial, and subcutaneous external sphincter muscles.

Pelvic Organs.—The structures most commonly involved by primary rectal cancer are the uterus, vagina, prostate gland, and seminal vesicles. The assessment of tumor abutment of the presacral fascia and involvement of sacral nerve roots is also important for surgical planning. Tumor extension into the proximal sacrum or nerve root involvement above the S2 vertebral level may render the tumor unresectable.

Anal Sphincter.—The anal sphincter is composed of a smooth muscle internal sphincter and an external sphincter complex composed of skeletal muscle. The internal sphincter is a continuation of the circular muscle layer of the rectum, whereas the longitudinal muscle layer continues as the intersphincteric plane between the internal and

external 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. 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. This relationship is best evaluated on coronal images. Tumor involvement of the anal sphincter complex may require partial sphincter resection with coloanal reconstruction, whereas extensive involvement will preclude sphincter preservation (Fig 9).

Pelvic Sidewall.—The structures along the pelvic sidewall in proximity to the rectum include the common, external, and internal iliac vessels; the ureters; the piriformis muscle; the internal obturator muscle; and, in the region of the sci-

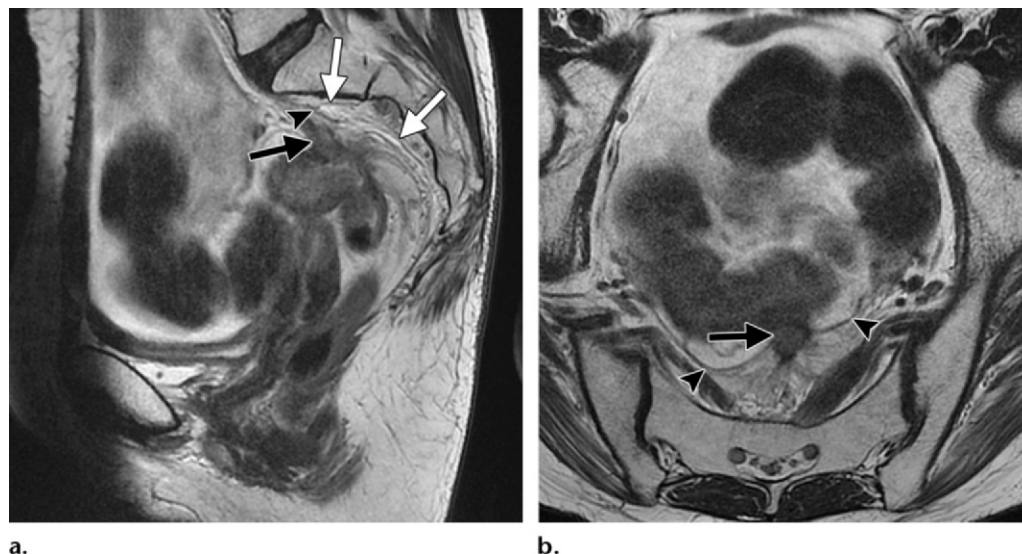


Figure 10. Relationship of tumor to the pelvic sidewall. Sagittal (**a**) and orthogonal axial (**b**) high-resolution T2-weighted MR images show a high rectal tumor (black arrow) infiltrating through the posterior rectal wall and involving the mesorectal fascia (arrowheads), which is separated from the presacral fascia (white arrows in **a**) by the retrorectal space.

atic foramen, exiting sacral nerve roots. These structures are covered by the endopelvic fascia, also called the parietal layer of the pelvic fascia. In some areas, particularly at the level of the upper rectum, this layer is either in proximity to or fused with the mesorectal fascia, also called the visceral layer of the pelvic fascia. In the presacral region, there is a presacral fascia, which is a continuation of the parietal pelvic fascia that covers the sacral nerve roots and sacral veins. The mesorectal fascia runs along the anterior aspect of the presacral fascia and is separated from it by a potential retrorectal space, which forms the plane of dissection in TME. At the level of the midrectum, the visceral and parietal layers of the endopelvic fascia can generally be identified as separate and distinct entities on MR images. However, in the lower and upper rectum, these structures may be indistinguishable. In these regions, tumor involvement of the mesorectal fascia may equate to pelvic sidewall involvement.

The assessment of the relationship between tumor and the pelvic sidewall is best made on coronal or sagittal high-resolution images, since findings on routine large-FOV images can easily lead to underestimation of tumor proximity to critical pelvic sidewall structures such as vessels or nerve roots (Fig 10).

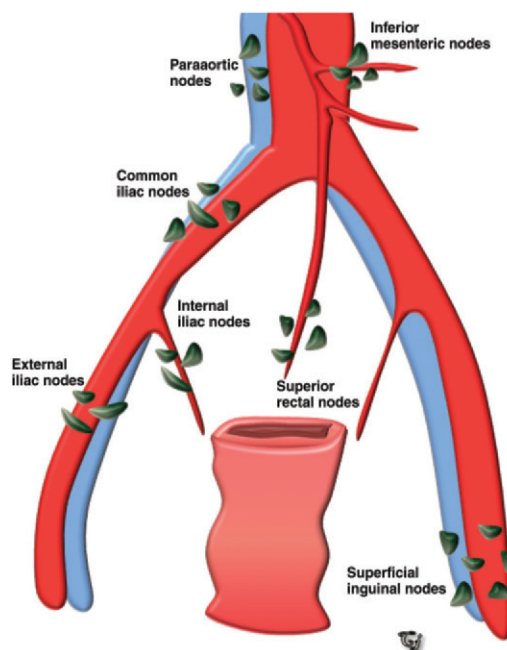
Vascular Invasion

Although vascular invasion does not affect treatment decision making and is assessed at pathologic analysis, it has prognostic significance and, if possible, should be evaluated at imaging (Fig 11). Generally, small-vessel involvement is difficult to assess, and the involvement of larger vessels such as the midrectal or superior rectal arteries or veins is suggested by the visualization of tumor in the vessel lumen on contiguous sections (16).

Figure 11. Vascular invasion in an advanced-stage rectal tumor. Sagittal high-resolution T2-weighted MR image shows a large high rectal tumor (black arrow) with extensive infiltration into the mesorectal fat. The tumor abuts the mesorectal fascia (arrowhead) anterior to the sacrum. There is evidence of vascular invasion (white arrow), with tumor identified in the lumen of the superior rectal vessels.



Figure 12. Drawing illustrates the most common nodal pathways of tumor spread in rectal cancer. The most common pathway of nodal spread from all primary rectal tumors is to mesorectal nodes, followed by spread to superior rectal and inferior mesenteric nodes. Midrectal tumors also spread through lymphatic vessels along the midrectal vessels to internal iliac nodes, whereas low rectal tumors may also involve superficial inguinal nodes.



Assessment of Nodal Involvement

The assessment of lymph node involvement in primary rectal cancer involves evaluation of the following nodal groups: mesorectal, superior rectal, and inferior mesenteric; internal, external, and common iliac; retroperitoneal; and superficial inguinal (Fig 12).

Nodes within the confines of the mesorectal fascia are resected during TME. These nodes should be assessed in terms of their involvement (ie, benign or malignant) and the relationship of clearly malignant nodes to the mesorectal fascia. If a malignant node or tumor deposit abuts (ie, is less than 1 mm from) the mesorectal fascia, this information is important to the surgeon, who must stay well clear of the tumor at that margin. In the United States, nodes outside the mesorectal fascia

along the pelvic sidewall are not routinely resected. However, if involvement of these nodes can be established preoperatively, it is important to modify the treatment approach to avoid recurrence in untreated nodes. Involved extramesorectal lymph nodes can be targeted with a widened field for preoperative radiation therapy and extended surgical resection. Moreover, it is important to evaluate

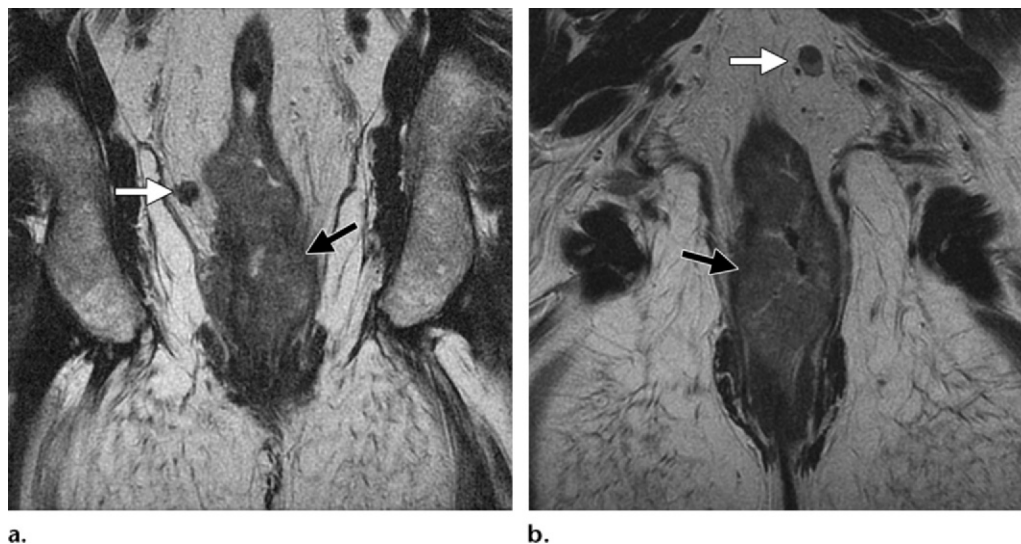


Figure 13. Mesorectal lymph node involvement. **(a)** Coronal high-resolution T2-weighted MR image shows a low rectal tumor (black arrow) extending into the anal canal. A mesorectal node with an irregular margin and heterogeneous signal intensity (white arrow) is seen to the right of the rectum, a finding that is consistent with metastatic adenopathy. **(b)** Coronal high-resolution T2-weighted MR image shows a low rectal tumor (black arrow). A mesorectal node with heterogeneous signal intensity (white arrow) is seen to the left of the rectum, a finding that is also consistent with metastatic adenopathy.



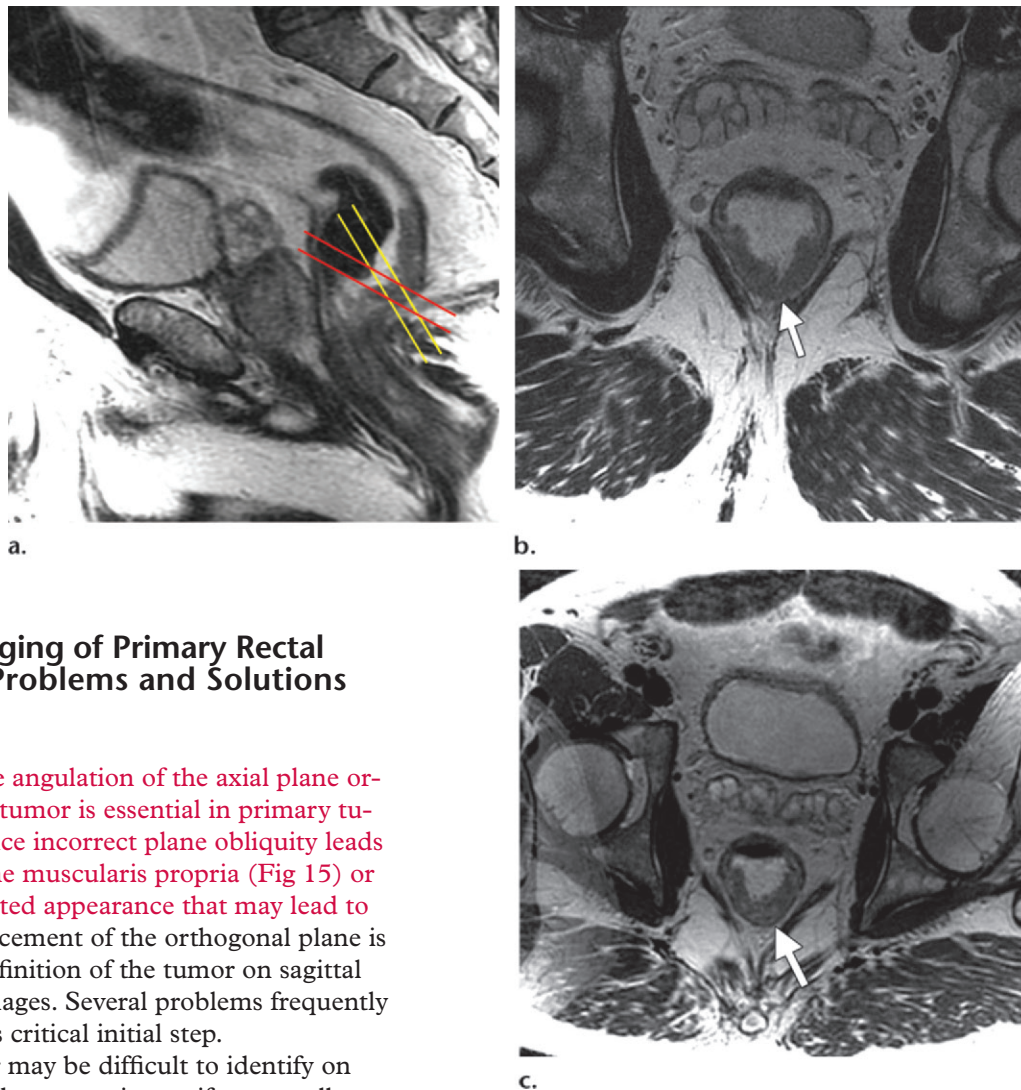
Figure 14. Pelvic sidewall lymph node involvement. Coronal high-resolution T2-weighted MR image shows an enlarged left obturator node with heterogeneous signal intensity (white arrow) superior to the obturator artery (black arrow).

these nodes for the purposes of staging, since malignant external iliac and superficial inguinal nodes imply stage M1 disease.

It is well established that nodal size is of limited value in assessing for the presence of metastasis. The most frequently used size criterion for distinguishing malignant from nonmalignant

nodes (ie, 5 mm) has a sensitivity of 68% and a specificity of about 78% (3,17). The limited accuracy of nodal size is likely related to the fact that 30%–50% of metastases in rectal cancer occur in nodes that are less than 5 mm (18,19). Recently, it was reported that nodal margins and internal nodal characteristics are the most reliable indicators of malignancy (3). Features that are suggestive of malignancy include irregular or spiculated nodal margins and heterogeneous signal intensity (Fig 13). The evaluation of these features requires high-resolution images that cover all nodes of importance, including superior rectal and pelvic sidewall adenopathy (Fig 14).

Figure 15. Importance of appropriate angulation of orthogonal axial planes for high-resolution T2-weighted MR imaging of rectal tumors. **(a)** Sagittal T2-weighted MR image shows a mass along the posterior wall of the lower rectum. Red lines = incorrect angulation relative to the lower portion of the tumor, yellow lines = correct angulation. **(b)** Incorrectly angulated axial high-resolution T2-weighted MR image shows blurring of the muscularis propria (arrow), resulting in inaccurate staging. **(c)** Correctly positioned axial high-resolution T2-weighted MR image shows an intact muscularis propria (arrow), a finding that confirms a stage T2 tumor confined within the rectal wall.



MR Imaging of Primary Rectal Cancer: Problems and Solutions

Problems

The appropriate angulation of the axial plane orthogonal to the tumor is essential in primary tumor staging, since incorrect plane obliquity leads to blurring of the muscularis propria (Fig 15) or a pseudospiculated appearance that may lead to overstaging. Placement of the orthogonal plane is based on the definition of the tumor on sagittal T2-weighted images. Several problems frequently arise during this critical initial step.

1. The tumor may be difficult to identify on sagittal images due to motion artifacts, small tumor size, or intrinsic low contrast between the tumor and the rectal wall on fast relaxation fast spin-echo (FSE) T2-weighted images.
2. Redundancy and tortuosity of the rectum can compromise the accurate positioning of the orthogonal plane.
3. Large polypoid masses, such as villous tumors, may make it difficult to define the site of

origin of the tumor from the rectal wall and to position the orthogonal plane appropriately.

In addition, there are limitations to obtaining high-resolution images in the axial plane alone.

1. Nodes along the pelvic sidewall and superior rectal vessels may fall outside the FOV of axial high-resolution images. Because characterization of nodes relies on the definition of nodal contour and internal signal characteristics, which

Table 2
MR Imaging Protocol for Primary Rectal Cancer

Parameter	Imaging Sequence					
	Sagittal T2W	Axial T2W	Oblique Axial Thin-Section T2W	Coronal Thin-Section T2W	T2W CUBE	Axial Diffusion-weighted
Pulse sequence	FRFSE	FSE	FRFSE	FRFSE	3D FSE T2W CUBE	DWI-EPI*
Echo time (msec)	102	102	102	102	Variable	75
Repetition time (msec)	>3000	~4000	4500	4500	2000	1200
Echo train length	12–16	16	12–16	12–16	56	...
Bandwidth (kHz)	31.25	41.70	27.80	27.80	31.25	250.00
FOV (cm)	20–24	32	18	18	22	32
Section thickness (mm)	3	5	3	3	2	5
Spacing/no. of locations	0	0	0	0	0/58–64	0
Matrix	256 × 256	320 × 256	256 × 256	256 × 256	256 × 256	160 × 200
No. of signals acquired	3	2	4	4	1	4 (all)
Phase FOV (cm)	1.0	0.7–1.0	1.0	1.0	1.0	0.8–1.0
Frequency direction	Anterior to posterior	Right to left	Anterior to posterior	Superior to inferior	Superior to inferior	Right to left
Saturation	Anterior if frequency direction is superior to inferior	Anterior	Anterior if frequency direction is right to left	...	Right, left, posterior, anterior, superior, inferior	...
Acquisition time	4 min 8 sec	5 min 30 sec	6 min 25 sec	6 min	7 min	2 min 30 sec

Note.—DWI = diffusion-weighted imaging, EPI = echoplanar imaging, FRFSE = fast relaxation fast spin-echo, T2W = T2-weighted.

* $b = 500\text{--}1000\text{ sec/mm}^2$.

requires high-resolution imaging, nodes excluded from the FOV are not adequately evaluated.

2. Tumor involvement of the peritoneal reflection and pelvic sidewall is most easily assessed on sagittal or coronal high-resolution images. If high-resolution images are obtained in the axial plane alone, this assessment, which is critical for staging and surgical planning, may be compromised.

Solutions

We use a number of solutions to address the aforementioned commonly encountered problems in the MR staging of rectal cancer, including (a) high-resolution T2-weighted images obtained in

the sagittal and coronal planes in addition to the orthogonal axial plane, (b) rectal gel to assist in defining small tumors and the site of attachment of polypoid tumors to the rectal wall, (c) diffusion-weighted images to assist in defining the primary tumor and nodes, and (d) 3D FSE T2-weighted sequences to allow acquisition of high-resolution and multiplanar reformatted images.

Table 2 shows the imaging protocol for primary rectal cancer that we have developed at our institution. This imaging protocol has been developed for a 1.5-T GE imager with HDxt 15.0 software (GE Healthcare, Waukesha, Wis). It incorporates fast relaxation FSE T2-weighted sequences with an

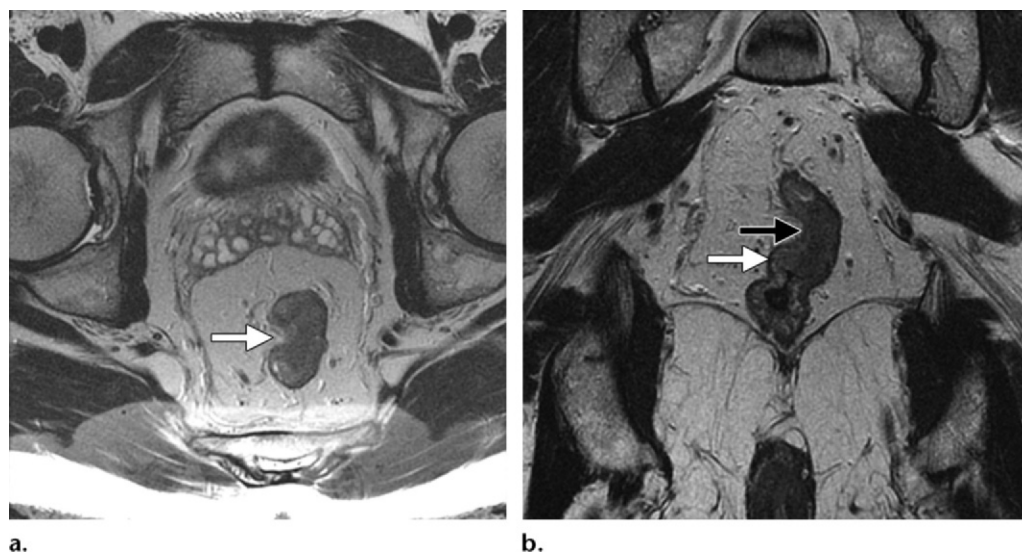


Figure 16. Value of high-resolution multiplanar imaging. **(a)** Axial high-resolution T2-weighted MR image shows a villous tumor arising from the right rectal wall, with loss of the muscularis propria (arrow) and possible tumor extension into the mesorectal fat. **(b)** Coronal high-resolution T2-weighted MR image shows a sharp curvature (black arrow) at the base of the villous tumor, where placement of the orthogonal axial plane is difficult and may yield misleading results. The image also clearly depicts the muscularis propria (white arrow), which is involved but not breached by the tumor.

echo time of approximately 100 msec. We do not routinely use FSE T2-weighted sequences for the high-resolution images; however, this is a matter of preference, and either sequence may be used.

The protocol shown in Table 2 is based on the use of high-resolution multiplanar imaging, rectal contrast material, diffusion-weighted imaging, and 3D T2-weighted imaging.

High-Resolution Multiplanar Imaging.—We recommend that high-resolution T2-weighted images be obtained in three planes: the sagittal and coronal planes, in addition to the axial plane orthogonal to the tumor. This approach improves confidence in the assessment of tumor stage because the relationship of the tumor to the muscularis propria can be confirmed in three planes. This is of particular value in the imaging of tortuous rectal tumors, in which accurate positioning of the axial plane is difficult and determination of the depth of penetration through the muscularis propria may rely on the high-resolution sagittal and coronal views (Fig 16).

High-resolution multiplanar imaging provides superior evaluation of the relationship of tumor to the peritoneal reflection, a factor that is important in tumor staging, since invasion of the peritoneal reflection upgrades the tumor to a stage T4 lesion (Fig 17). We have frequently ob-

served that this relationship is better defined on coronal images than on sagittal images because the former are less frequently degraded by motion artifacts.

As has been reported in previous articles, coronal high-resolution T2-weighted images are essential for assessing the relationship of tumor to the anal sphincter; however, instead of obtaining coronal images parallel to the tumor plane, we obtain straight coronal high-resolution images of the pelvis (20). The straight coronal images provide definition of the anatomy of the anal sphincter and of the relationship of the tumor to the sphincter, with the added benefits of assessment of tumor relationship to the pelvic sidewall and peritoneal reflection, as well as evaluation of pelvic sidewall nodal morphology. They improve assessment of the relationship of the tumor to the pelvic sidewall because subtle strands of tumor infiltration that can be missed on large-FOV T2-weighted images are easily identified on high-resolution images (Fig 18).

High-resolution multiplanar imaging allows evaluation of all mesorectal nodes, superior rectal nodes, and internal and external iliac nodes with the degree of resolution required to assess nodal morphology (Fig 14). This has the potential to improve specificity in the assessment of nodal involvement by extending the criteria for mesorectal nodal evaluation to include pelvic sidewall nodal assessment (3).



Figure 17. Value of high-resolution multiplanar imaging. **(a)** Routine sagittal T2-weighted MR image shows a circumferential tumor (black arrow) involving the rectosigmoid junction. There is possible involvement of the peritoneal reflection (white arrows); the muscularis propria is not clearly defined at the point where the colon abuts the peritoneum. **(b)** Sagittal high-resolution T2-weighted MR image shows an intact muscularis propria (arrowhead) between the tumor and the peritoneal reflection (white arrows), a finding that was confirmed at surgery. The tumor invades through the muscularis propria (black arrow) only along the anterior wall of the colon.

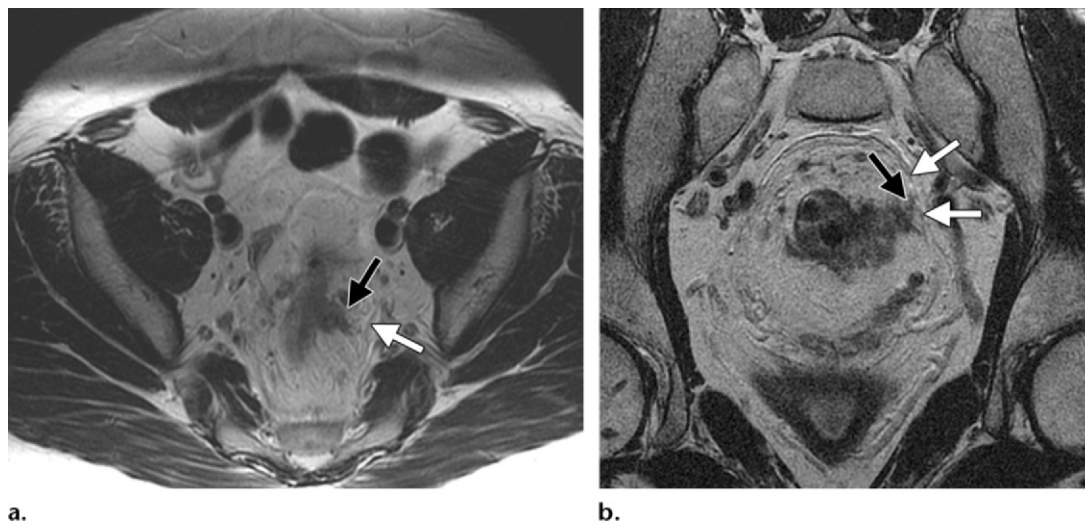


Figure 18. Assessment of the relationship between tumor and the pelvic sidewall. **(a)** Routine axial T2-weighted MR image (36-cm FOV, 5-mm section thickness) shows tumor infiltration of the mesorectal fat (black arrow) that appears to be separated from the mesorectal fascia-parietal pelvic fascia along the pelvic sidewall (white arrow) by an intervening fat plane. **(b)** Coronal high-resolution T2-weighted MR image shows that the tumor infiltration of the mesorectal fat (black arrow) abuts the mesorectal fascia-parietal pelvic fascia along the pelvic sidewall (white arrows).

It is also important to further qualify the placement of the orthogonal axial plane. In most patients, this plane is placed perpendicular to the axis of the rectum, with coverage of the tumor occasionally requiring the acquisition of multiple sets of oblique orthogonal images (20). Occasion-

ally, however, the rectal walls may not be parallel to each other or to the axis of the rectal lumen, in which case the orthogonal plane should be placed perpendicular to the rectal wall from which the tumor arises, thereby improving tumor staging.

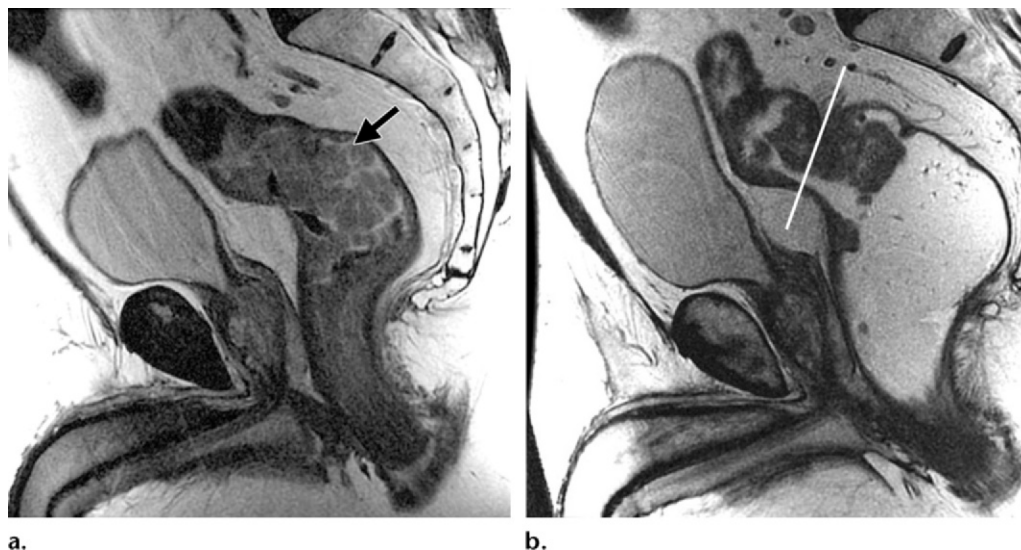


Figure 19. Benefit of using rectal gel. **(a)** Sagittal high-resolution T2-weighted MR image does not clearly show the site of origin of a villous tumor (arrow) from the rectal wall, making it difficult to determine the appropriate placement of the orthogonal plane. The depth of tumor invasion should be evaluated at the site of the tumor's origin from the rectal wall. **(b)** Sagittal high-resolution T2-weighted MR image obtained after the introduction of rectal gel clearly depicts the area of tumor origin from the rectal wall, allowing appropriate placement of the orthogonal planes (white line).

Use of Rectal Contrast Material.—The use of rectal contrast material in the staging of primary rectal cancer is controversial. A potential limitation of its use is that distention of the rectum may alter the distance between the tumor and the mesorectal fascia. In addition, its use may be associated with an increase in motion artifacts related to sphincter contraction that would degrade image quality. In our experience, however, these problems do not arise if an appropriate amount (60–100 mL) of warm US gel is used. The amount of gel used should be tailored to the location of the tumor, with smaller amounts being used for midrectal tumors and larger amounts for outlining high rectal tumors. Although the use of rectal contrast material does not provide any additional benefit in the staging of large rectal tumors, there is a subset of patients in whom it has proved valuable, including patients with polypoid tumors (eg, villous adenomas), small rectal tumors (<3 cm), or a history of prior therapy (eg, partial resection or radiation therapy).

In polypoid masses, the gel delineates the tumor and allows definition of the site of tumor attachment to the rectal wall. This step assists

in the appropriate positioning of the orthogonal plane for axial high-resolution T2-weighted imaging (Fig 19). In smaller and treated tumors, it may be difficult to define the location of the primary tumor. This difficulty is partially related to size but also exists because the intrinsic signal intensity characteristics of rectal tumors on fast relaxation FSE T2-weighted images obtained on our MR imager are frequently similar to those of the adjacent rectal wall, and, in the absence of a clearly defined mass, the tumor may be difficult to identify. Every effort should be made to ensure delineation of the tumor, which is crucial for appropriate positioning of the orthogonal plane.

The use of rectal gel is not recommended for low rectal tumors because distention of the rectum can efface the small amount of perirectal fat around the lower rectum and obscure nodes in the lower mesorectum.

Diffusion-weighted Imaging.—The poor contrast of rectal tumors on fast-relaxation FSE T2-weighted images remains a problem in tumor definition. There has been some research suggesting that diffusion-weighted imaging can improve the detection of colorectal tumors (21). At our institution, we have found that diffusion-weighted imaging can assist in the localization of tumor

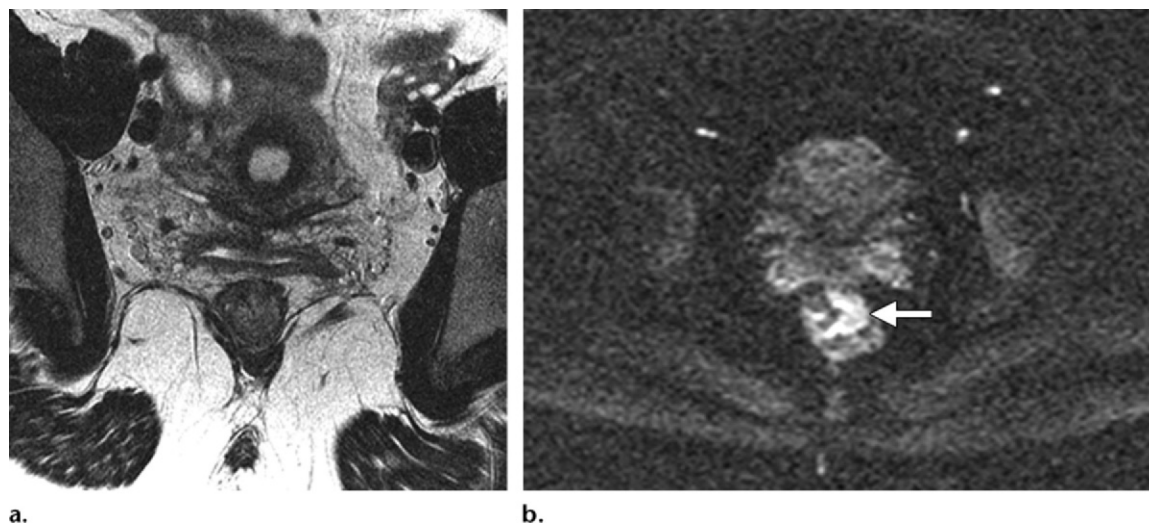


Figure 20. Utility of diffusion-weighted imaging. (a) Axial T2-weighted MR image through the rectum does not define the primary tumor. (b) Axial diffusion-weighted image ($b = 500 \text{ sec/mm}^2$) depicts a small hyperintense tumor (arrow) along the left rectal wall.

and nodal spread (Fig 20). However, a significant limitation of diffusion-weighted imaging is that the primary tumor is frequently obscured by susceptibility artifacts from bowel gas.

In terms of nodal involvement, diffusion-weighted imaging serves as a useful “cheat sheet” for detecting lymph nodes; however, it appears to have limited value for characterizing nodes because of overlap in the apparent diffusion coefficient (ADC) values of malignant and hyperplastic benign nodes (22).

We acquire diffusion-weighted images with a 200×160 matrix, a 30–40-cm FOV, a 6-mm section thickness, a b value of 500–800 sec/mm^2 , diffusion gradient application only in the superior-inferior direction, the acquisition of four signals, and a repetition time and echo time of 1800 and 75 msec, respectively. We generate diffusion-weighted images with section levels that correspond to the large-FOV axial T2-weighted images. This technique enables us to combine areas of high signal intensity seen on the diffusion-weighted images with the anatomic definition seen on the T2-weighted images, allowing accurate localization of regions defined at diffusion-weighted imaging. The coverage on these images extends to the origin of the inferior mesenteric artery, located at the L3 vertebral level, so as to allow identification of the most superior extent of the most common pathways of nodal spread from primary rectal tumors.

Diffusion-weighted imaging has the additional value of being potentially useful in predicting response to chemotherapy on the basis of ADC values. Dzik-Jurasz et al (23) reported that a low ADC value is predictive of a good response to treatment, possibly reflecting a greater responsiveness to radiation therapy for highly cellular tumors than for necrotic lesions. In addition, ADC value is an early marker of tumor response to chemotherapy–radiation therapy: Cell death, which can be detected as an increase in ADC value, precedes alterations in tumor size (24).

Three-dimensional T2-weighted Imaging.—

Three-dimensional T2-weighted imaging permits the use of thin (1–2-mm) sections with no inter-section gap, which provides superb anatomic detail. In addition, images obtained with this technique may have a superior signal-to-noise ratio (SNR) and contrast compared with two-dimensional (2D) T2-weighted images (25). The higher SNR is because there is no cross talk between sections and because of the additional sampling due to phase encoding in the third dimension. In our experience, this allows better delineation of the submucosa and muscularis propria, and also yields superior contrast between the tumor and the rectal wall (Fig 21). However, other studies have reported 3D T2-weighted imaging to yield

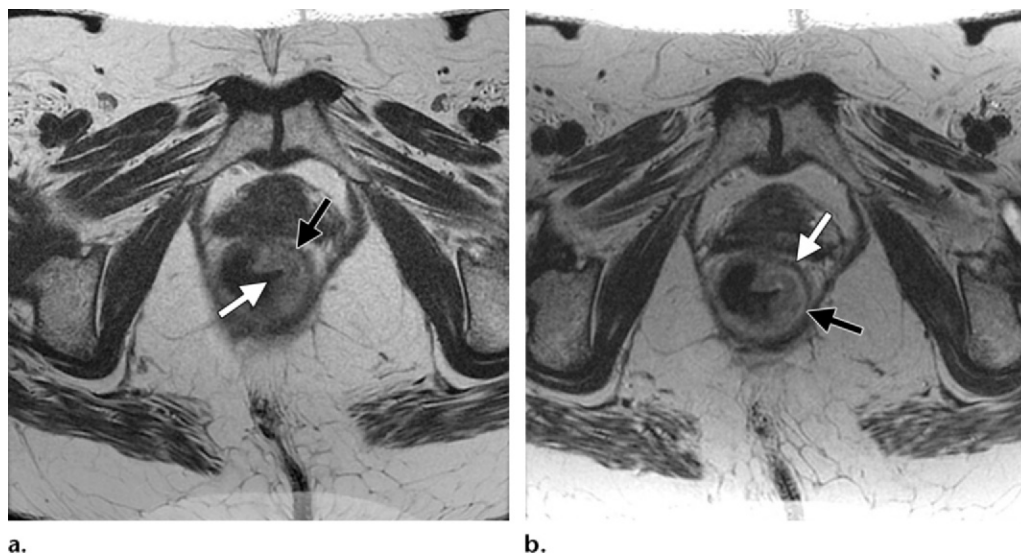


Figure 21. Benefit of 3D T2-weighted MR imaging. **(a)** Axial 2D high-resolution T2-weighted MR image shows an ulcerated low rectal tumor (white arrow) along the left rectal wall with possible invasion of the muscularis propria (black arrow), suggesting a stage T2 tumor. **(b)** Orthogonal axial 3D T2-weighted MR image (18-cm FOV, 256 × 256 matrix, 2-mm section thickness) has a superior SNR, which permits delineation of the submucosa as a thin hyperintense line (black arrow) between the tumor and an uninvolved muscularis propria (white arrow), allowing the correct diagnosis of a stage T1 tumor.

Table 3
Suggested Checklist for Use Prior to MR Imaging of Rectal Cancer

Review prior images and clinical history
Check for history of prior therapy (eg, partial resection or chemoradiotherapy)
Define location and size of tumor
Request that patient empty the bladder and rectum before getting on the table
Administer 60–120 mL of warm gel (amount depends on tumor location) in patients with small (<2-cm) tumors, villous tumors, or a history of prior therapy
Position the eight-channel cardiac coil correctly relative to tumor location
After performing initial sagittal T2-weighted imaging, mark the plane for placement of orthogonal axial images of the tumor

lower tumor conspicuity than 2D T2-weighted imaging. This observation is likely dependent on many factors, such as (a) section thickness; (b) use of parallel imaging, which reduces the SNR; and (c) the type of MR imaging unit used (26).

Three-dimensional T2-weighted imaging also allows multiplanar reformation. However, small-FOV images are difficult to obtain, since, with the software currently available at our institution, this technique is not amenable to no-phase wrap. In addition, with 2-mm-thick acquisitions, which yield nonisotropic voxels, multiplanar reformat images obtained away from the plane of acquisition are blurred. The use of thinner (1–1.2-

mm) sections is frequently associated with a prolonged imaging time as well as a decreased SNR. Because 3D images obtained away from the plane of acquisition are frequently blurred, we obtain 3D images in the same plane used to obtain the orthogonal 2D high-resolution T2-weighted images. Coverage with the orthogonal 3D volume is generally greater than that with the 2D T2-weighted imaging because the sections at either end of the 3D volume of acquisition are generally degraded by aliasing artifact. We perform this sequence in addition to 2D high-resolution T2-weighted imaging because 3D T2-weighted imaging occasionally provides additional information, since the submucosa and muscularis propria are frequently better defined with the 3D sequences.

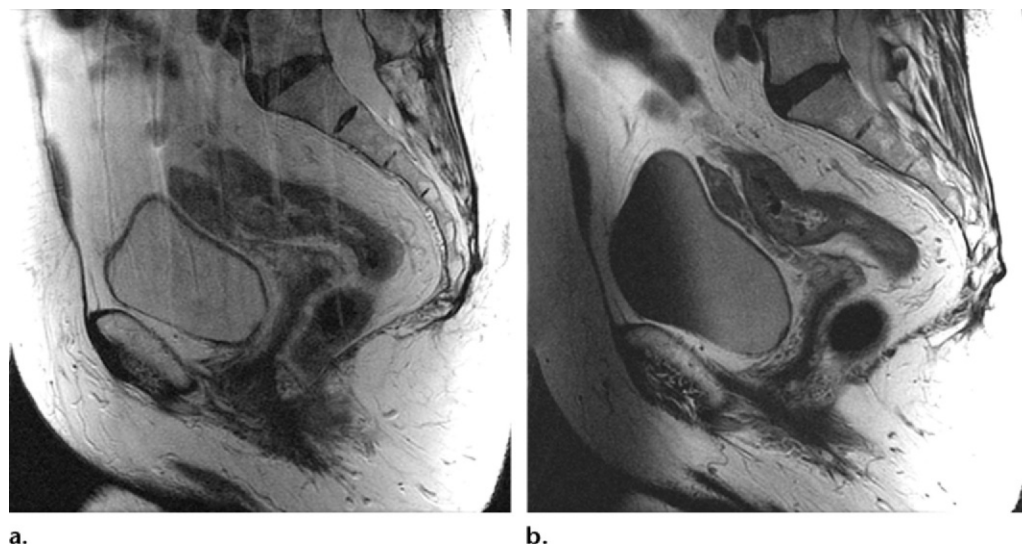


Figure 22. Optimization of image quality with an anterior saturation band. **(a)** Sagittal T2-weighted MR image is degraded by motion artifacts from the anterior abdominal wall, which limits evaluation of the primary tumor. **(b)** On a sagittal T2-weighted MR image obtained after placement of a wide anterior saturation pulse over the anterior abdominal wall, the anterior saturation band suppresses fat signal and significantly improves image quality.

Practical Guidelines for Obtaining Good-Quality MR Images

The ability to stage rectal tumors accurately is entirely dependent on the acquisition of good-quality images, the likelihood of which can be increased by *(a)* carrying out preimaging patient assessment and *(b)* addressing certain technical challenges.

Preimaging Patient Assessment

Obtaining good-quality MR images requires that a number of steps be taken before placing the patient in the imager (20). We have found that adhering to the checklist shown in Table 3 improves both image quality and the consistency with which good-quality images are obtained.

In the preimaging assessment, it is important for the attending radiologist to have as much information as possible about the size and location of the primary tumor. This is to ensure that rectal contrast material is administered if the radiologist anticipates either that *(a)* a small or partially treated tumor may be difficult to see, or *(b)* the point of attachment of a polypoid tumor to the rectal wall may be difficult to define. Information about tumor location assists in positioning the surface coil, which should be moved a few inches higher or lower depending on whether the tumor is high or low in the rectum. The issue of defining the primary tumor has been addressed in previous studies with use of bowel preparation with bisacodyl or glycerine enemas, rectal con-

trast material in the form of ferristene enemas, and spasmolytics. In our practice, we do not use a bowel preparation or spasmolytics, and the use of rectal contrast material is limited because it prolongs imaging time and may alter the distance to the potential CRM.

The current consensus does not favor the use of intravenous contrast material for the staging of primary rectal cancer, and its use is not part of our imaging protocol (27).

Technical Challenges

The most commonly encountered technical problems are related to motion artifacts and a suboptimal SNR (20).

Motion Artifacts.—Motion artifacts are most commonly seen on sagittal and orthogonal axial images. They are related to motion of the anterior abdominal wall, bowel, or bladder and can significantly compromise image quality.

A proposed solution to anterior abdominal wall motion artifacts is placement of a saturation pulse across the anterior abdominal wall (Fig 22)—more specifically, a wide band placed obliquely, covering the entirety of the abdominal wall fat and encroaching onto the anterior aspect of the abdomen (20). An alternative solution is to swap phase and frequency, with an anterior-to-posterior frequency direction. The disadvantage

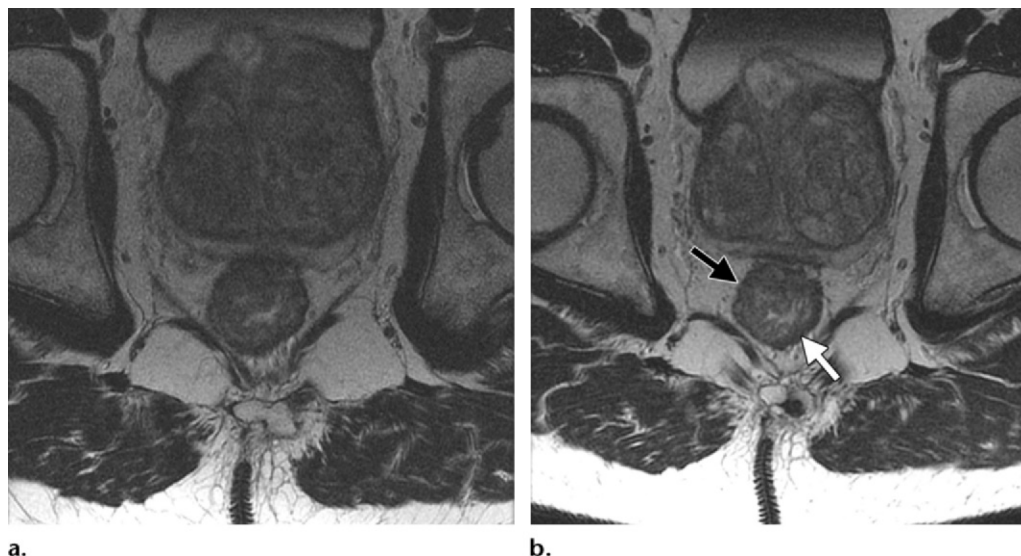


Figure 23. Optimization of image quality. **(a)** Axial high-resolution T2-weighted MR image (16-cm FOV, 320×256 matrix) has a poor SNR, which compromises assessment of a tumor and the muscularis propria. **(b)** Axial high-resolution T2-weighted MR image obtained with a larger FOV (18 cm) and a smaller matrix (256×256) has a better SNR and clearly depicts the tumor (black arrow) and the muscularis propria (white arrow).

of this second solution is that the no-phase wrap function has to be applied with a decrease in signal intensity. Any effort to offset this by increasing the number of signals acquired requires a greater time expenditure.

Although we do not routinely use bowel paralytics, this is an area that requires evaluation. Generally, with a superior-to-inferior phase direction, motion artifacts from the bowel and bladder do not pass through the rectum; however, depending on the location of small bowel loops, image quality may be compromised by peristalsis. We have also found that coronal images are not often degraded by motion artifacts and may serve in a backup capacity.

Suboptimal SNR.—The SNR frequently suffers in the effort to obtain high-resolution images. This can significantly compromise image quality and render the imaging study nondiagnostic. The goal is to find an appropriate balance between the FOV and matrix and to achieve a voxel size of 0.6–0.8 mm. This balance must be optimized for each MR imager. On our imager, the preferred FOV range is 16–18 cm (we generally use an FOV of 18 cm), with a matrix of at least 256×256 and the ac-

quisition of four signals using the no-phase wrap function (Fig 23). We also keep the bandwidth at 15.63–31.25 kHz. Appropriate positioning of the surface coil (we use an eight-channel cardiac coil at our institution) relative to the tumor is important in improving the SNR (20).

Conclusions

Although orthogonal axial high-resolution T2-weighted images are the cornerstone for staging primary rectal cancer, sagittal and coronal high-resolution images provide additional value, particularly in tumors arising in a redundant tortuous rectum. Coronal high-resolution T2-weighted images also improve the assessment of nodal morphology, particularly for superior rectal and pelvic sidewall nodes, and of the relationship between advanced-stage tumors and adjacent pelvic structures. Rectal gel should be used for the staging of polypoid tumors, previously treated lesions, and small rectal tumors. However, its use should be avoided in large and low rectal tumors. Diffusion-weighted imaging is useful for identifying nodes and, occasionally, the primary tumor when it is difficult to see with other sequences. Three-dimensional T2-weighted imaging provides multiplanar capability with a superior SNR compared with 2D T2-weighted imaging.

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MR Imaging for Preoperative Evaluation of Primary Rectal Cancer: Practical Considerations

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High-resolution T2-weighted imaging is the key sequence in the magnetic resonance (MR) imaging evaluation of primary rectal cancer. This sequence generally consists of thin-section (3-mm) axial images obtained orthogonal to the tumor plane, with an in-plane resolution of 0.5–0.8 mm.

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Recent studies have shown that high-resolution MR imaging is a reliable and reproducible technique with high specificity (92%) for predicting a negative CRM, the relationship of the tumor to the CRM, and the depth of tumor invasion outside the muscularis propria (2,8,9).

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However, the assessment of nodal involvement remains a confounding factor. Patients with malignant adenopathy should receive chemotherapy–radiation therapy; however, cross-sectional imaging relies on size as a criterion for nodal involvement, which has significant limitations. High-resolution MR imaging allows the assessment of nodal morphology, which significantly improves specificity in the assessment of nodal involvement. One limitation is the significant learning curve, as shown by the difficulty in reproducing the high sensitivity reported by Brown et al (3,10).

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It appears that, although MR imaging is accurate in advanced stage T3 tumors, considerable experience and good-quality images are required to assess the subtle findings that help distinguish early stage T3 tumors from stage T2 tumors.

Page 400 (Figure on page 400)

The appropriate angulation of the axial plane orthogonal to the tumor is essential in primary tumor staging, since incorrect plane obliquity leads to blurring of the muscularis propria (Fig 15) or a pseudospiculated appearance that may lead to overstaging.