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MRI of Rectal Cancer: An Overview and Update on Recent Advances

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OBJECTIVE. MRI is the modality of choice for rectal cancer staging. The high soft-tissue contrast of MRI accurately assesses the extramural tumor spread and relation to mesorectal fascia and the sphincter complex. This article reviews the role of MRI in the staging and treatment of rectal cancer. The relevant anatomy, MRI techniques, preoperative staging, post–chemoradiation therapy (CRT) imaging, and tumor recurrence are discussed with special attention to recent advances in knowledge.

CONCLUSION. MRI is the modality of choice for staging rectal cancer to assist surgeons in obtaining negative surgical margins. MRI facilitates the accurate assessment of mesorectal fascia and the sphincter complex for surgical planning. Multiparametric MRI may also help in the prediction and estimation of response to treatment and in the detection of recurrent disease.

Keywords: chemoradiation therapy, MRI, rectal cancer, recurrence, staging

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Rectal cancer—defined as cancer (usually adenocarcinoma) occurring in the distal 15 cm of the intestinal tract as measured to or from the anal verge—is one of the major causes of cancer-related mortality worldwide [1]. Although imaging can be suggestive of the diagnosis of rectal cancer, particularly when obstruction hinders endoscopic access or biopsy fails, the primary role of imaging is to assist in treatment triage of histologically diagnosed tumors. Surgical resection with negative margins (i.e., no tumor extension within 1 mm of the resected margins on histology [2]) is the only standard locally curative therapy for rectal cancer. Failure to attain negative margins (i.e., positive postoperative margins) often results in tumor recurrence and the possibility of incurable disease, a poor quality of life, and reduced disease-free survival [3].

The initial local staging is performed to determine which patients require preoperative chemoradiation therapy (CRT) or to plan surgery in those not requiring CRT with the intent to obtain a negative margin. For tumors in the upper two thirds of the rectum, the standard procedure is low anterior resection (LAR) with total mesorectal excision wherein the rectum (except the distal portion) and the surrounding mesorectum are removed [4]. For tumors in the distal one third of the rectum, depending on local extension, sphincter-sparing surgeries (e.g., ultra-LAR or intersphincteric resection) or abdominoperineal resection (APR) surgeries are attempted [5]. Post-CRT staging aims at assessing treatment response; knowing the post-CRT stage is important for selecting further treatment such as surgical resection or extended CRT.

Transrectal ultrasound (TRUS) is an accurate imaging modality for differentiating T1 from T2 tumors and is similar to MRI in differentiating T2 from T3 tumors [6–8]. However, at higher disease stages, MRI is better than TRUS in the assessment of the tumoral border and mesorectal fascia (MRF), surrounding viscera, and pelvic nodes. In addition, dynamic contrast-enhanced (DCE) MRI can provide functional information that may predict response to treatment or help detect recurrent disease [9–19]. CT is not suitable for T staging of rectal cancer because of its lower contrast resolution, but it is the preferred modality for detecting distant metastasis, especially when combined with PET [20]. Currently, MRI is the imaging modality of choice for the local evaluation of rectal cancer [7].

Rectal MRI Techniques

MRI performed at a higher field strength benefits from faster image acquisition, higher spatial resolution, and higher signal-to-noise ratio (SNR), which may improve the visibility of the rectal wall. However, studies of 3-T MRI for rectal cancer staging have not yet shown any significant improvement with re-

TABLE 1: Sample MRI Parameters (1.5 T) for Staging Rectal Cancer

MRI Parameter	FSE T2-Weighted Imaging				DWI[a]	3D T1-Weighted Gradient-Refocused Echo[b]
	Sagittal	Axial	Coronal	High-Resolution Oblique		
TR (ms)	3500	3320	3500	4000	5800	4.44
TE (ms)	91	91	91	80	96	1.59
No. of slices	28	40	25	15	30	32
Bandwidth (Hz/pixel)	391	391	391	391	1132	400
FOV (mm)	220	220	220	200	250	240
Slice thickness (mm)	3	4	4	3	4	4
Distance factor (%)	25	25	25	0	20	20
Phase FOV (%)	100	100	100	100	100	100
No. of acquisitions	3	2	2	3	6	1
Matrix	350 × 320	350 × 320	350 × 320	350 × 320	250 × 250	240 × 240
Phase-encoding direction	AP	Transverse (R > L)	Transverse (R > L)	AP	AP	AP
Saturation band	Anterior	NA	NA	Superior and inferior	NA	NA
Acquisition time (min)	4	5.5	4	5	4.5	1
Base resolution	320	320	320	320	192	320
Voxel size (mm)	0.7 × 0.7 × 4.0	0.7 × 0.7 × 4.0	0.7 × 0.7 × 4.0	0.6 × 0.6 × 3.0	1.7 × 1.3 × 4.0	0.9 × 0.8 × 4.0

Note—FSE = fast spin-echo, DWI, AP = anteroposterior, NA = not applicable.
[a]The following b values were used: 0, 50, 400, and 800 s/mm^2.
[b]Unenhanced and three contrast-enhanced phases.

spect to the differentiation of T2 tumors from early T3 tumors [21]. The current studies in the literature show that, if the imaging parameters are appropriately adjusted, both 1.5- and 3-T machines can be used with comparable accuracies for staging rectal cancer [7].

New pelvic phased-array multichannel coils provide high spatial resolution, high SNR, and larger-FOV imaging for visualization of the lateral pelvic structures and lymph nodes [22]. Although endorectal coils provide higher resolution of the rectal wall, they are not in common use because of patient and cost factors. Bowel preparation is generally not necessary before the examination, but antispasmodic agents are useful for decreasing bowel peristalsis and resultant motion artifacts and, therefore, are generally advised unless contraindicated. Filling of the rectal lumen with gel or contrast material probably facilitates the detection of small tumors. However, compression of the mesorectal fat due to rectal distention may critically alter the staging because it leads to underestimation of the distance of the tumor to MRF and possibly to nonvisualization of the mesorectal nodes [23]; therefore, the routine use of endorectal filling is not recommended [7].

The rectal MRI protocol at our institution includes multiplanar conventional and high-resolution oblique T2-weighted and axial T1-weighted pulse sequences and multiparametric MRI sequences including diffusion-weighted imaging (DWI) and contrast-enhanced MRI. The mandatory part of this protocol is T2-weighted imaging; the other sequences are optional when the MRI examination must be shortened. A sidewall-to-sidewall sagittal T2-weighted sequence provides the initial images for localizing the tumor, and axial and coronal T2-weighted imaging should be performed in the same manner. Then, high-resolution oblique T2-weighted images with thin (3 mm) slices and a large matrix size (e.g., 320 × 320) should be obtained perpendicular to the tumoral axis in the sagittal view in one or more planes depending on the size and shape of the tumor [24] (Fig. 1). High-resolution oblique imaging provides the optimal anatomic information for an improved assessment of the depth of invasion and of tumoral relationships especially anteriorly and in relation to the sphincter complex and levator muscle in patients with low rectal tumors [24, 25]. The use of T1-weighted imaging for rectal cancer staging is recommended mainly for the evaluation of coincidental findings and the pelvic bones. DWI may help in the assessment of response to CRT [9–13] and may improve the accuracy of MRI for the detection of rectal cancers and involved pelvic nodes [26, 27].

Currently there is no agreement with regard to the role of gadolinium-enhanced MRI in patients with rectal cancer [7]. However, it may improve the detection of tumors and malignant lymph nodes [28–30], increase the accuracy of MRI for diagnosing T3 tumors [31] and locoregional extensions, and help in the assessment of treatment response after CRT [17, 18]. In addition, the DCE-MRI–derived quantitative parameters that represent the tumor microcirculation may help in the prediction of the status of the circumferential resection margin (CRM), the presence of metastases, and response to CRT [14–19, 32–34]. A recent meta-analysis [35] showed that multiparametric MRI had a promising role in restaging of rectal cancer after preoperative CRT through a more accurate diagnosis of nodal disease and in predicting and detecting good treatment response. In our experience, contrast-enhanced MRI may also facilitate the assessment of extramural vascular invasion (EMVI) and T4 tumors and characterization of coexistent pelvic abnormalities. The parameters of a suggested optimal rectal MRI protocol are summarized in Table 1.

MRI for Initial Staging of Rectal Cancer

MRI staging of rectal cancer comprises the assessment of tumor location and relationship

to MRF and sphincters, tumor size, extent of extramural spread (T stage), peritoneal reflection, EMVI, lymph nodes, and bony metastasis. We think that a structured synoptic MRI report (Appendix 1) is better than the descriptive report form because it ensures that all necessary characteristics are included and are addressed objectively and because it is preferred by most treating physicians.

For tumor localization, the distance of the lowest portion of the tumor from the anal verge is measured. A rectal tumor is characterized as low, middle, or high when its most caudal border is less than 5 cm from the anal verge, 5–10 cm from the anal verge, or more than 10 cm from the anal verge, respectively. In the lower parts of the rectum, the mesorectal fat surrounding the rectum is circumferentially bound by MRF. However, in higher portions, the peritoneum starts covering the anterior part of mesorectal fat to a point called the "anterior peritoneal reflection." Upward from the anterior peritoneal reflection, the peritoneum gradually extends posteriorly and finally encircles the rectosigmoid. The peritoneal reflection appears as a thin (1–2 mm) hypointense line on T2-weighted imaging that attaches the anterior aspect of the rectum and should be assessed in both the axial and sagittal planes. On sagittal images, the peritoneal reflection may be depicted above the tip of the seminal vesicles in men and at the uterocervical angle in women [24] (Fig. 2). The relationship of tumor to and invasion of the peritoneal reflection should be carefully reported. Low rectal cancers should be differentiated from anal squamous cell carcinomas before MRI interpretation; this distinction is possible only by histopathologic results and not by location and is important because the staging, behavior, and management of these entities are markedly different [36].

Mucinous rectal adenocarcinomas have higher metastatic tendency and often have a higher stage at the time of diagnosis [37]. Although the diagnosis of mucinous adenocarcinoma is primarily based on histology, sampling issues could lead to failure of diagnosis [38]; therefore, differentiation of mucinous rectal adenocarcinomas from nonmucinous subtypes should be attempted on MRI based on hyperintensity on T2-weighted imaging and on apparent diffusion coefficient (ADC) [39].

T Stage for Middle Tumors and High Tumors

On T2-weighted imaging, the muscularis propria appears as a hypointense line between the hyperintense mesorectal fat and the inner submucosa and mucosa, which show intermediate to mild hyperintensity (Fig. 2). The signal intensity of a rectal tumor on T2-weighted images is typically intermediate between the signal intensity of the muscularis propria and mucosa. Differentiation of T1 tumors from T2 tumors on MRI is usually not reliable without an endorectal coil, and tumors should be generally staged as "T1/T2." A tumor is staged as T3 when it invades the mesorectal fat. Disruption of the muscularis propria because of the penetrating vessels should not be overstaged as T3 [40]. Spiculation of the mesorectal fat can be caused by either a benign desmoplastic reaction, seen as low signal intensity on T2-weighted images (T2 tumor), or tumor extension, seen as intermediate signal intensity on T2-weighted images (early T3 tumor), and may not be easily differentiated from one another on MRI (Fig. 3). However, preoperative CRT is not considered critical in patients with early T3 tumors without risks of positive margins [41].

For T3 tumors, the shortest distance between the most penetrating parts of the tumor and the MRF should be measured (Fig. 3). The MRF is not circumferential at or above the peritoneal reflection and here it covers the posterior or posterolateral aspects of mesorectal fat of the rectum (Fig. 4). The MRF is best visualized on T2-weighted images as a hypointense line surrounding the mesorectal fat especially at the proximal and posterior portions of the rectum where fat tissue is more abundant (Fig. 2). A tumor–MRF distance of more than 1 mm is a reliable predictor for negative margins after total mesorectal excision [42]. In the presence of satellite nodules, the shortest distance between the nodules and the MRF should also be reported.

The extramural depth of invasion refers to extension of tumor beyond the muscularis propria and is a prognostic factor. The American Joint Committee on Cancer [43] suggested an optional stratification of T3 tumors based on the extramural depth of invasion: less than 5 mm, T3a; 5–10 mm, T3b; and more than 10 mm, T3c (Table 2). An extramural depth of invasion of less than 5 mm confers a significantly higher survival rate, and these early T3 tumors may be adequately managed with surgery alone and have a prognosis comparable to that of tumors characterized as "T1/T2" [44].

If a tumor invades the visceral peritoneum, it is staged as T4a. Therefore, accurate depiction of the peritoneal reflection on MRI is crucial for proper staging of rectal tumors. Tumors that invade other structures or adjacent organs are staged as T4b (Fig. 5).

T Stage for Low Tumors

The surgical approach for low rectal tumors is more complex than for middle and high rectal tumors because of the thinner mesorectum and the presence of the surrounding sphincter complexes. The internal sphincter is a smooth-muscle ring formed by the inner (circular) muscle layer of the rectum. The external sphincter complex is a group of voluntary muscles in continuation of the levator muscles and consisting of the puborectalis and external sphincter muscles. Given the shape and anatomic location of the levator muscles, their accurate assessment in relation to the tumor is optimal through an evaluation of coronal and sagittal images.

Low rectal tumors typically undergo standard LAR, intersphincteric resection, or APR (Fig. 6). The proximity of the inferior border of the tumors to the top border of the anal sphincters accounts for the selection of sphincter-preservation surgery and should be measured for low rectal tumors. Accordingly, a staging system geared toward staging low rectal cancers has been devised [40] (Table 2). Consideration should be given to assessing the lateral extent of the tumor in the perineum so that a wide APR can be planned to ensure negative margins (Fig. 7). APR is required for advanced T2 tumors, T3 tumors, and high rectal tumors that involve the levator muscles. In patients with adjacent organ invasion, pelvic exenteration may be indicated [45].

N Stage

The extent of nodal disease is important for both choosing and planning preoperative CRT and surgery [46]. In the TNM system, disease involving only the regional nodes, including the mesorectal and internal iliac nodes, accounts for the N stage; involvement of other nodes is regarded as metastasis [43] (Table 2). Mesorectal nodes are often the first and the most common group of nodes that are involved. Nodal metastases are usually within the proximal 5 cm of the tumor [47]. Extramesorectal nodes are generally involved in locally advanced cancers [46]. Inguinal nodal metastases, which are more typical of anal cancer than of rectal cancer, are uncommon even in low rectal cancers and imply poor prognosis [48].

Currently, size (i.e., short axis) and morphologic criteria are used with variable sensitivities (56–94%) and specificities (67–83%)

TABLE 2: Staging Systems for Rectal Cancer

Stage	Description
T stage for middle tumors and high tumors[a]	
T1	Tumor invades submucosa
T2	Tumor invades muscularis propria
T3	Tumor invades through muscularis propria to pericolorectal tissues
a	Tumor < 5 mm into the perirectal fat or extramural
b	Tumor 5–10 mm into the perirectal fat or extramural
c	Tumor > 10 mm into the perirectal fat or extramural
T4	Organ invasion
a	Tumor penetrates to surface of visceral peritoneum
b	Tumor directly invades or is adherent to other organs or structures
T stage for low tumors[b]	
T1	Tumor confined to bowel wall but does not extend through full thickness; intact outer muscle coat
T2	Tumor replaces muscle coat but does not extend into intersphincteric plane
T3	Tumor invades intersphincteric plane or lies within 1 mm of levator muscle
T4	Tumor invades external anal sphincter and is within 1 mm and beyond levator muscle with or without invading adjacent organs
N stage	
Nx	Regional lymph nodes cannot be assessed
N0	No regional lymph node metastasis
N1	Metastasis in 1–3 regional lymph nodes
N2	Metastasis in > 3 regional lymph nodes
M stage	
M0	No distant metastasis
M1	Distant metastasis
a	Metastasis confined to 1 organ or 1 site
b	Metastasis in more than 1 organ, 1 site, or peritoneum

Note—[a]Adapted from a Radiological Society of North America (RSNA) Radiology Reporting Template developed at the RSNA by the RSNA Radiology Reporting Committee and its subspecialty subcommittees and provided under license from RSNA [94]: Radiological Society of North America website. Hussain S, et al. MR rectum cancer. www.radreport.org/template/0000068. Published December 1, 2009. Updated July 16, 2012)
[b]Adapted from [40]: Taylor FG, Swift RI, Blomqvist L, Brown G. A systematic approach to the interpretation of preoperative staging MRI for rectal cancer. *AJR* 2008; 191:1827–1835.

for the differentiation of benign from malignant nodes [49, 50]. Although metastatic nodes are generally larger than benign nodes, malignant disease may be present even in very small nodes. The most commonly advocated size cutoffs for the diagnosis of malignancy are in the range of 5–8 mm [7]; however, adding morphologic features, such as irregular contour and mixed signal intensity, to a size cutoff increases the diagnostic accuracy [51] (Fig. 8). Craniocaudal localization and clock-face localization of suspicious lymph nodes relative to the tumor are necessary; for mesorectal nodes, the distance to the MRF should also be measured.

DWI has shown low to moderate sensitivity (67–78%) and specificity (60–67%) for detecting involved lymph nodes [52, 53]. Although the combination of DWI with T2-weighted imaging has improved identification of metastatic lymph nodes in pelvic cancers [26], this combination is not considered reliable for the differentiation of benign from malignant lymph nodes in patients with rectal cancer [7].

MRI with lymph node–specific contrast agents has shown good diagnostic performance for the characterization of lymph nodes. Ultrasmall superparamagnetic iron oxide (USPIO) is an iron-based nanoparticle that is taken up by normal cells and decreases the signal intensity of normal cells on T2- and T2*-weighted imaging; as a result, malignant nodes, which do not uptake USPIO particles, look brighter than benign nodes and enhance relative to normal tissues. The intensity and pattern of USPIO uptake, or lack thereof, have been shown to have moderate to high accuracy (sensitivity, 60–100%; specificity, 91–94%) for identifying malignant lymph nodes [54, 55]. Currently, the only U.S. Food and Drug Administration–approved and commercially available USPIO is ferumoxytol [56].

Gadofosveset is a gadolinium chelate that reversibly binds to albumin and exhibits a long intravascular half-life [57]. Normal or reactive lymph nodes uptake gadofosveset and enhance like vessels, but nodes with malignant infiltration show less enhancement with promising results [58]. However, the interpretation of these findings for nodes in the superior mesorectum or those in the vicinity of vessels is challenging, and the presence of micrometastases cannot be ruled out [29].

FDG PET has high specificity (85–95%) for the identification of malignant nodes, but its role in nodal staging is limited because of low sensitivity (29–63%) and the inability to accurately localize the involved nodes [59–61]. FDG PET is more suitable for the assessment of extramesorectal nodes because high uptake of tracer by the primary tumor may prevent the visualization of mesorectal nodes [62]. Application of CT with PET improves the ability of the modality for anatomic localization. PET/CT has shown 63–70% accuracy for the detection of regional lymph node metastasis, and the combination of high-resolution MRI with PET/CT increases the accuracy up to 90% [49].

Extramural Vascular Invasion

EMVI refers to the extension of rectal tumor into the veins beyond the muscularis propria and can be detected on MRI with moderate sensitivity and high specificity by visualizing the vessels close to the tumor; EMVI is suggested when vessels close to the tumor are obviously irregular or expanded by tumoral signal intensity [63] (Fig. 9). EMVI has been accepted as an independent prognostic indicator in colorectal cancer that is associated with a higher incidence of metastasis, local recurrence, poorer response to preoperative CRT, and overall lower survival rate [63–65]. Recently, the rate of metachronous metastasis [66] and response to preoperative CRT [67] have been shown to be associated with the size of the involved vessels.

EMVI assessment is not included in the TNM staging system. However, EMVI status on initial MRI staging has been suggested by some studies as a prognostic factor for the stratification of patients for selecting the appropriate treatment, especially for indicating adjuvant therapy and its intensity [68].

Assessment of Response

Preoperative neoadjuvant CRT has improved the survival of patients possibly by increasing the CRM-negative resections [69]. In addition, it may enable sphincter-preserving resection in patients with low rectal tumors through downstaging of locally advanced disease [70]. The post-CRT restaging MRI examination is performed with the intent to, again, ensure negative margins, select patients with preexisting morbidities for local or less radical excision, and reassess patients for interval development of metastasis and extramesorectal lymphadenopathy. Tumor restaging involves correlating the posttreatment images with the pretreatment images with respect to all the elements assessed in the initial staging and necessitates image acquisition with almost the same protocol and on the same planes [71] (Fig. 10).

TABLE 3: MRI Grading for Rectal Tumor Regression

Grade	Degree of Response	Description
1	Complete	No evidence of treated tumor
2	Good	Dense fibrosis or mucin; no obvious residual tumor
3	Moderate	> 50% Fibrosis or mucin and visible intermediate signal intensity
4	Slight	Little areas of fibrosis or mucin; mostly tumor
5	None	Same appearance and signal intensity as original tumor

Note—Adapted from [40]: Taylor FG, Swift RI, Blomqvist L, Brown G. A systematic approach to the interpretation of preoperative staging MRI for rectal cancer. *AJR* 2008; 191:1827–1835.

One of the most important parameters in restaging is reassessment of the MRF. MRI has shown approximately 76% sensitivity and 86% specificity for the assessment of the MRF in the irradiated pelvis [72]. However, the accuracy of MRI for restaging is generally lower than the accuracy of MRI for initial staging mainly owing to overstaging of nodal disease, failure to differentiate tumoral infiltration or residual tumor from desmoplastic reaction or radiation fibrosis, and misinterpretation of radiation proctitis as local invasion [73]. Evaluation of mucinous adenocarcinomas on posttreatment MRI is also considerably challenging because these tumors remain hyperintense on T2-weighted imaging regardless of their response to treatment [74].

A more extensive fibrosis in a postsurgical specimen is correlated with greater tumor regression and predicts a higher likelihood of survival [71]. Taylor et al. [40] have suggested a tumor regression grading system based on the extent of visible fibrosis on MRI (Table 3). However, MRI is not reliable for confirming complete response because of its inability to detect microscopic residual tumor or mucin lakes that can be detected at histopathology [13]; therefore, caution should be exercised in claiming "complete response" on post-CRT MRI reports.

Although MRI restaging of rectal cancer with the conventional protocol is based on morphologic findings and changes in anatomic measurements, DWI and DCE-MRI may potentially provide functional information that can be correlated with changes at the cellular level in response to treatment. After CRT, the decrease in cellularity and the development of fibrosis or necrosis in responders result in an increase in diffusion and increase in the ADC value [9–13]. A recent meta-analysis has shown that DWI is more sensitive than (62–94%) and is almost as specific as (74–91%) conventional MRI in restaging rectal tumors after CRT [72]. However, because mucinous tumors exhibit ADC hyperintensity even before treatment, their response to CRT cannot be assessed using DWI [75].

The persistence of EMVI after CRT can be detected on MRI and, regardless of the final pathologic staging, may predict a higher risk of metastatic disease and an overall shorter disease-free survival [67]. Therefore, EMVI status after CRT may possibly be used as an imaging biomarker for counseling patients for postoperative chemotherapy or more intensive surveillance.

In some studies, the intensity and pattern of enhancement with gadolinium or gadofosveset on T2-weighted imaging have been shown to be significant indicators of malignant nodes [28, 76]. However, a meta-analysis by van der Paardt et al. [72] showed a moderate specificity of 73% for nodal staging by MRI.

Recently, the results of two studies [17, 18] have suggested that the quantification of vascular permeability of the tumoral tissue represented as the K^{trans} (volume transfer constant) may aid in the prediction of pathologic response. These results showed that a large decrease in the mean K^{trans} after CRT is associated with a good response for locally advanced rectal tumors.

Overall, the diagnostic performance of MRI for restaging rectal cancer after CRT is heterogeneous. Although adding the multiparametric sequences may partly improve MRI accuracy, issues with nodal staging still exist [72].

Changes in cellular viability and metabolic activity after CRT can be depicted on PET and can be interpreted as a response to treatment (Fig. 10). PET has a high diagnostic performance for the interim assessment of response (sensitivity and specificity ≈ 80%)

but is less specific in post-CRT response assessment (≈ 60%) [77] and is less sensitive in the evaluation of mucinous tumors (≈ 50%), which uptake less tracer because of their lower cellular density [78].

Locoregional Recurrence

The incidence of recurrent rectal cancer has started declining in the most recent 2 decades because of the advent of adjuvant CRT and improvements in surgery. Pelvic recurrence occurs in approximately 4–8% of patients who undergo surgery performed with a curative intent, and most cases of pelvic recurrence are seen within the first 3 years after treatment [79]. The risk factors for local recurrence include CRM positivity, no preoperative radiotherapy, EMVI, perforation of the tumor at surgery, and close proximity of the tumor to the anal verge [80].

Most intraluminal recurrent tumors are diagnosed by either rectal examination or direct visualization on rectosigmoidoscopy; however, detection of extraluminal recurrence and differentiating extraluminal recurrence from postoperative changes may be possible only on imaging. MRI is the most accurate imaging modality for the evaluation of these patients [81], but its cost has limited its use for routine follow-up. Annual pelvic CT is included in some guidelines for the surveillance of patients after surgical resection of rectal cancer [82]. In other centers, pelvic imaging is performed only in the presence of suggestive clinical or laboratory findings (e.g., elevated serum carcinoembryonic antigen value).

Although T2-weighted imaging is considered the main sequence for the initial staging of rectal cancer, it is not specific enough for the assessment of recurrence. On T2-weighted images, recurring tumor appears hyperintense and is not distinguishable from inflammation or edema, which may persist for a few months after radiotherapy or surgery [83, 84]. On the other hand, fibrotic tissue may appear homogeneously hypointense on T2-weighted imaging while containing microscopic tumoral foci [85]. Currently, the most accurate MRI sequence for the differentiation of treatment-related changes from recurrent rectal cancer is contrast-enhanced imaging. Enhancement in tumoral tissue has been shown to occur earlier and to be more intense and heterogeneous than enhancement in benign posttreatment fibrosis [86, 87]. Besides its high diagnostic performance for the identification of distant metastatic disease in recurrent rectal cancer (sensitivity, 91%; specificity, 83%) [88], PET/CT has also shown high sensitivity (89–94%) and variable specificity (69–94%) for diagnosing the local recurrence on the basis of the shape, location, and intensity of tracer uptake [88–90]. Biopsy is indicated whenever imaging or clinical findings are equivocal and the diagnosis of recurrent disease cannot be confirmed.

Surgical resection with negative margins is established as the most efficient treatment for longer survival in recurrent rectal cancer [91]. However, assessment of local extension to adjacent structures is challenging because pelvic fat planes are no longer present or intact after surgery or radiotherapy. In this setting, local invasion can be suggested only when anatomic destruction or tumoral signal intensity is seen in the adjacent tissue. Detection of sacral invasion is crucial for achieving a clear posterior margin after resection. Whether radical exenterative surgery is a treatment option partly depends on the level of sacral involvement. In most institutions, invasion above the S2–S3 junction is a relative contraindication to resection, although high sacrectomy is also practiced in some centers [92].

A recent Delphi study by Chew et al. [93] has shown that colorectal surgeons rely on MRI findings more than other imaging modalities for determining the feasibility of resection with negative margins in patients with recurrent rectal cancer.

Conclusion

MRI is the modality of choice for staging rectal cancer to assist surgeons in obtaining negative surgical margins. MRI facilitates the accurate assessment of MRF and the sphincter complex for surgical planning. Multiparametric MRI may also help in the prediction and estimation of response to treatment and in the detection of recurrent disease.

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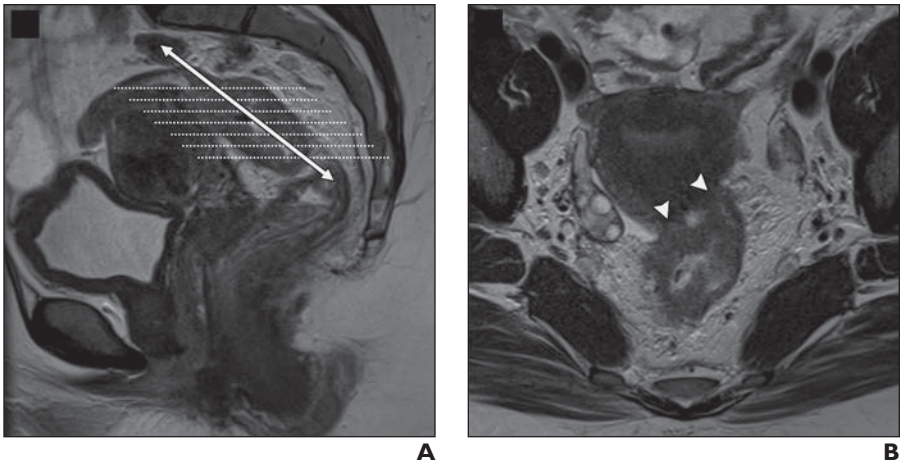
(Appendix and figures start on next page)

APPENDIX 1: Sample Template for Structured Synoptic Report of Rectal MRI

Items	Description
Image quality	☐ Adequate ☐ Suboptimal ☐ Nondiagnostic
Tumor location	
Distance of the lowest extent of tumor	From anal verge: _____ cm
	From top of the anal sphincter: _____ cm
Relationship to peritoneal reflection	☐ Above, ☐ At or straddle, ☐ Below, ☐ Not able to assess
Tumor characteristics	
Circumferential extent (clock face)	☐ Circumferential, ☐ Other: _____ o'clock
Craniocaudal extent	_____ cm
Mucinous	☐ No, ☐ Yes
T staging[a]	
Tumors above puborectalis	☐ T1/T2, ☐ T2/T3, ☐ T3, ☐ T3/T4, ☐ T4
Tumors below puborectalis	☐ T1, ☐ Early T2, ☐ Advanced T2, ☐ T3, ☐ T3/T4, ☐ T4
	Structures with possible invasion: _____
Mesorectal fascia and extramural depth of invasion	
Shortest distance of the definitive tumor border to the mesorectal fascia	_____ cm, ☐ Unable to estimate, ☐ Not applicable (T4)
Extramural depth of invasion at this level	_____ cm
Tumor spiculation closer to the mesorectal fascia	☐ No, ☐ Yes, distance: _____ cm, location: _____ o'clock
Other tumor component (any T2 or T3) closer to the mesorectal fascia	☐ No, ☐ Yes, distance: _____ cm, location: _____ o'clock
EMVI	☐ Absent, ☐ Equivocal, ☐ Present
Suspicious lymph nodes	
Mesorectal	☐ No, ☐ Yes (irregular border, mixed signal intensity, ≥ 5–8 mm)
Extramesorectal	☐ No, ☐ Yes (irregular border, mixed signal intensity, ≥ 5–8 mm)

Note—EMVI = extramural vascular invasion. (Adapted from [95]: Cancer Care Ontario website. Al-Sukhni E, Milot L, Fruitman M, et al. Synoptic MRI report for rectal cancer. https://www.cancercare.on.ca/common/pages/UserFile.aspx?fileId=133271)

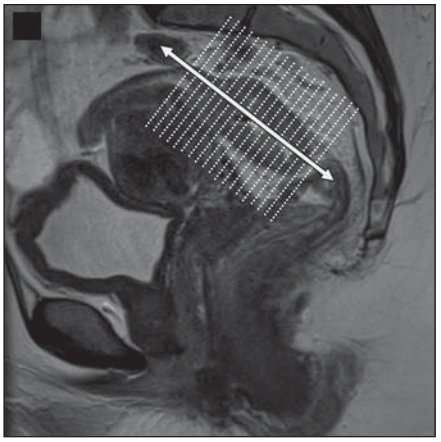
[a]T staging of rectal tumors is explained in Table 2.



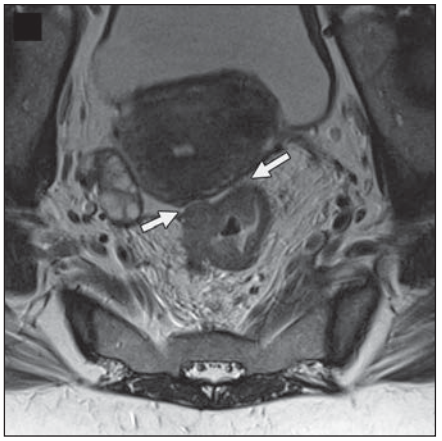
A **B**

Fig. 1—40-year-old woman with upper rectal cancer. This case shows impact of high-resolution oblique T2-weighted imaging on T staging.
A, Routine axial plane (*dotted lines*) planned on sagittal T2-weighted image. Arrow shows tumor axis.
B, On axial T2-weighted image, rectal tumor seems to invade posterior surface of uterus (*arrowheads*).

(Fig. 1 continues on next page)

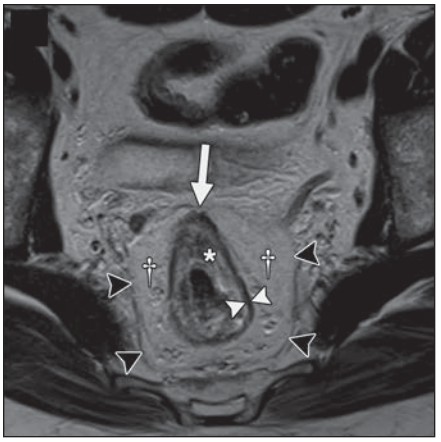


C

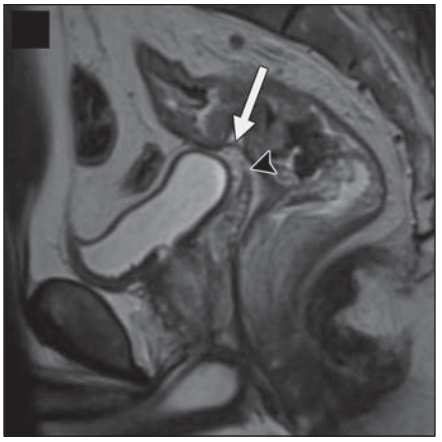


D

Fig. 1 (continued)—40-year-old woman with upper rectal cancer. This case shows impact of high-resolution oblique T2-weighted imaging on T staging.
C, Thinner slices with plane (*dotted lines*) perpendicular to axis of rectum and tumor (*arrow*) for high-resolution oblique imaging.
D, On high-resolution oblique T2-weighted image, there is no invasion of uterus with visible fat plane (*arrows*) between rectal cancer and uterus.

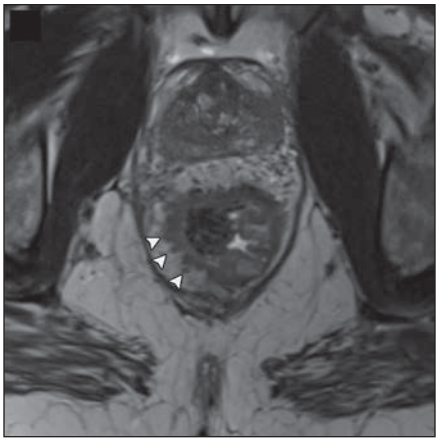


A

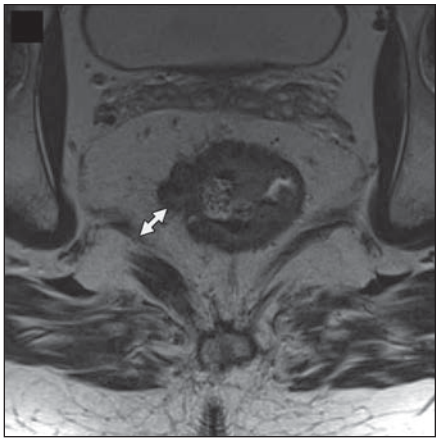


B

Fig. 2—Rectal anatomy on MRI. (Reprinted from [24] with permission: Furey E, Jhaveri KS. MRI in rectal cancer. *Magn Reson Imaging Clin N Am* 2014; 22:165–190, v–vi)
A, Axial T2-weighted image in 65-year-old man shows muscularis propria as hypointense band (*white arrowheads*) between mesorectal fat and submucosa (*asterisk*). Mesorectal fascia is depicted as thin hypointense line (*black arrowheads*) surrounding mesorectal fat (*daggers*). Note peritoneal attachment to anterior aspect of rectum (*arrow*).
B, Sagittal T2-weighted image in 52-year-old man shows peritoneal attachment (*arrow*) above tip of seminal vesicles (*arrowhead*).



A



B

Fig. 3—T3 rectal tumors on T2-weighted MR images.
A, Low rectal tumor in 58-year-old man with tumoral spiculations (intermediate signal intensity) of mesorectal fat (*arrowheads*).
B, Low rectal tumor in 63-year-old man with nodular extension to mesorectal fat. Double-headed arrow shows shortest distance from most penetrating part of tumor and mesorectal fascia.

(Fig. 3 continues on next page)

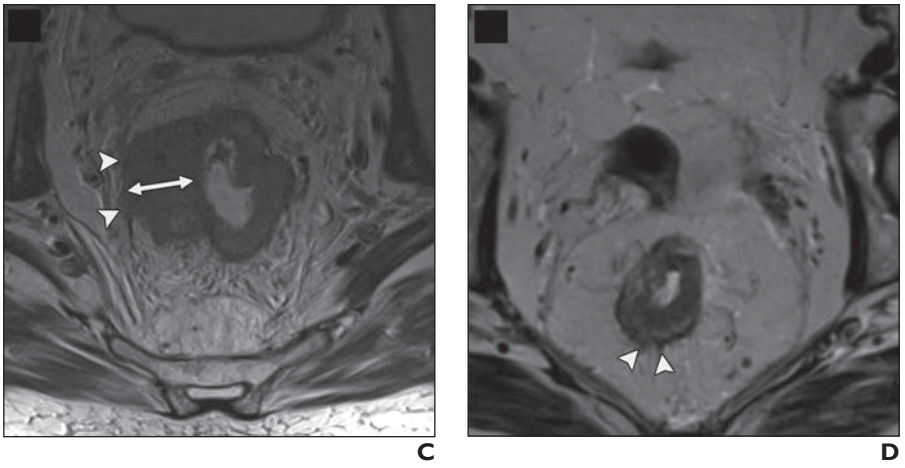


Fig. 3 (continued)—T3 rectal tumors on T2-weighted MR images.
C, Midrectal tumor in 80-year-old man with massive extension to mesorectal fat and mesorectal fascia infiltration (*arrowheads*). Double-headed arrow shows extramural depth of invasion.
D, Nontumoral spiculation (low signal intensity) of mesorectal fat without nodular extension to tumor (*arrowheads*) beyond muscularis propria in 67-year-old woman; pathology revealed T2 tumor. (Reprinted from [24] with permission: Furey E, Jhaveri KS. MRI in rectal cancer. *Magn Reson Imaging Clin N Am* 2014; 22:165–190, v–vi)

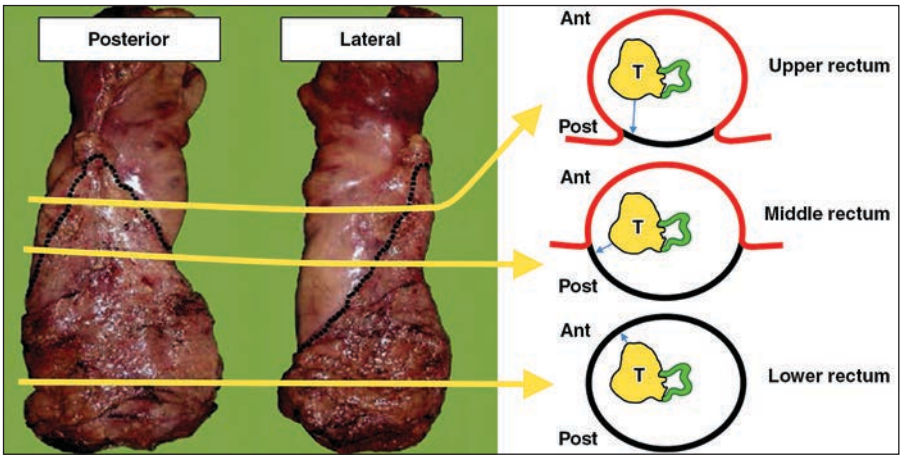


Fig. 4—Gross pathologic specimen of total mesorectal excision and axial schematic sections of rectum and mesorectum in 65-year-old man. Anterior and lateral aspects of upper rectum and anterior aspect of middle rectum are covered with peritoneum (*red line*). Shortest distance between tumor and circumferential resection margin (*blue arrows*) is measured as that between most penetrating part of tumor and mesorectal fascia not covered by peritoneum (*black line*). Ant = anterior, Post = posterior, T = tumor. (Photographs and drawings courtesy of Khalifa M, University of Toronto, Toronto, ON, Canada; and adapted from [24] with permission: Furey E, Jhaveri KS. MRI in rectal cancer. *Magn Reson Imaging Clin N Am* 2014; 22:165–190, v–vi)

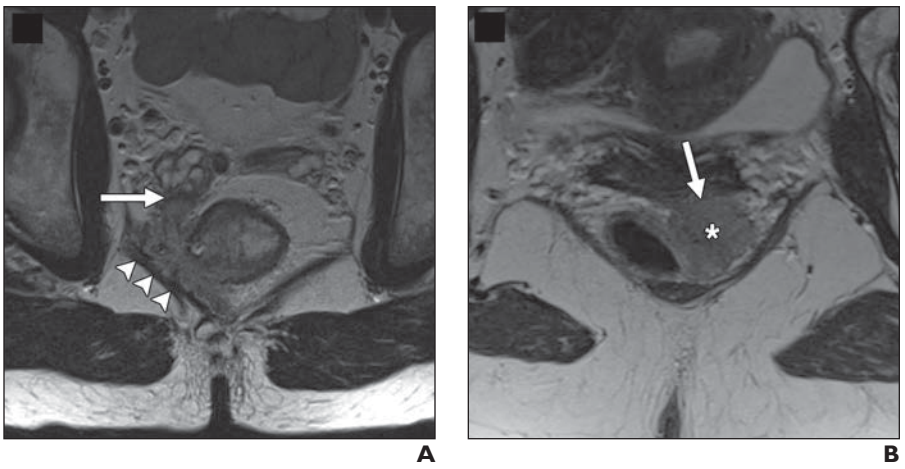


Fig. 5—High-resolution oblique T2-weighted images of two patients with T4 rectal tumors.
A, 40-year-old man with rectal tumor invading right seminal vesicle (*arrow*) and levator ani (*arrowheads*).
B, 53-year-old woman with rectal tumor (*asterisk*) invading left posterior vaginal wall (*arrow*).

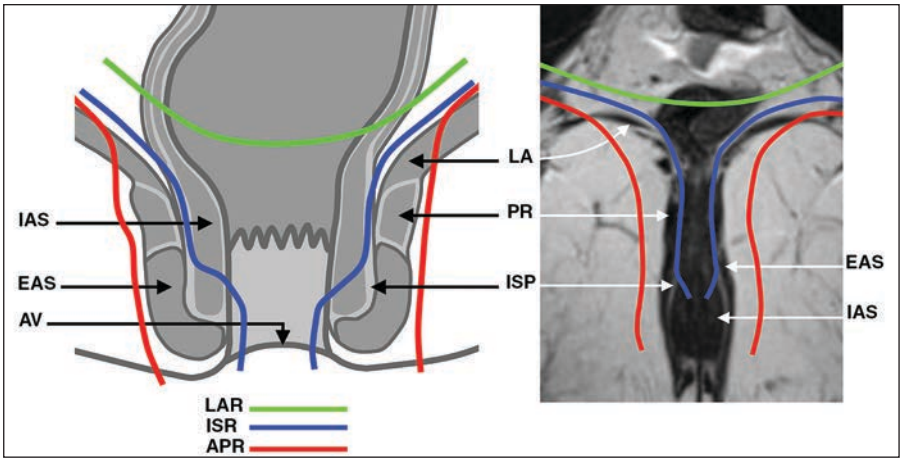


Fig. 6—Coronal schematic diagram of lower rectum (*left*) and MR image of lower rectum (*right*) in 58-year-old woman depict anal sphincter complex and surgical dissection planes. Standard low anterior resection (LAR) is reserved for mid- and high-rectal tumors without invasion to pelvic floor muscles. Intersphincteric resection (ISR) dissects internal anal sphincter at about level of dentate line. Abdominoperineal resection (APR) involves removal of rectum along with sphincter complex. AV = anal verge, EAS = external sphincter complex, IAS = internal anal sphincter, ISP = intersphincteric plane, PR = puborectalis, LA = levator ani. (Schematic diagram by Hosseini-Nik H)

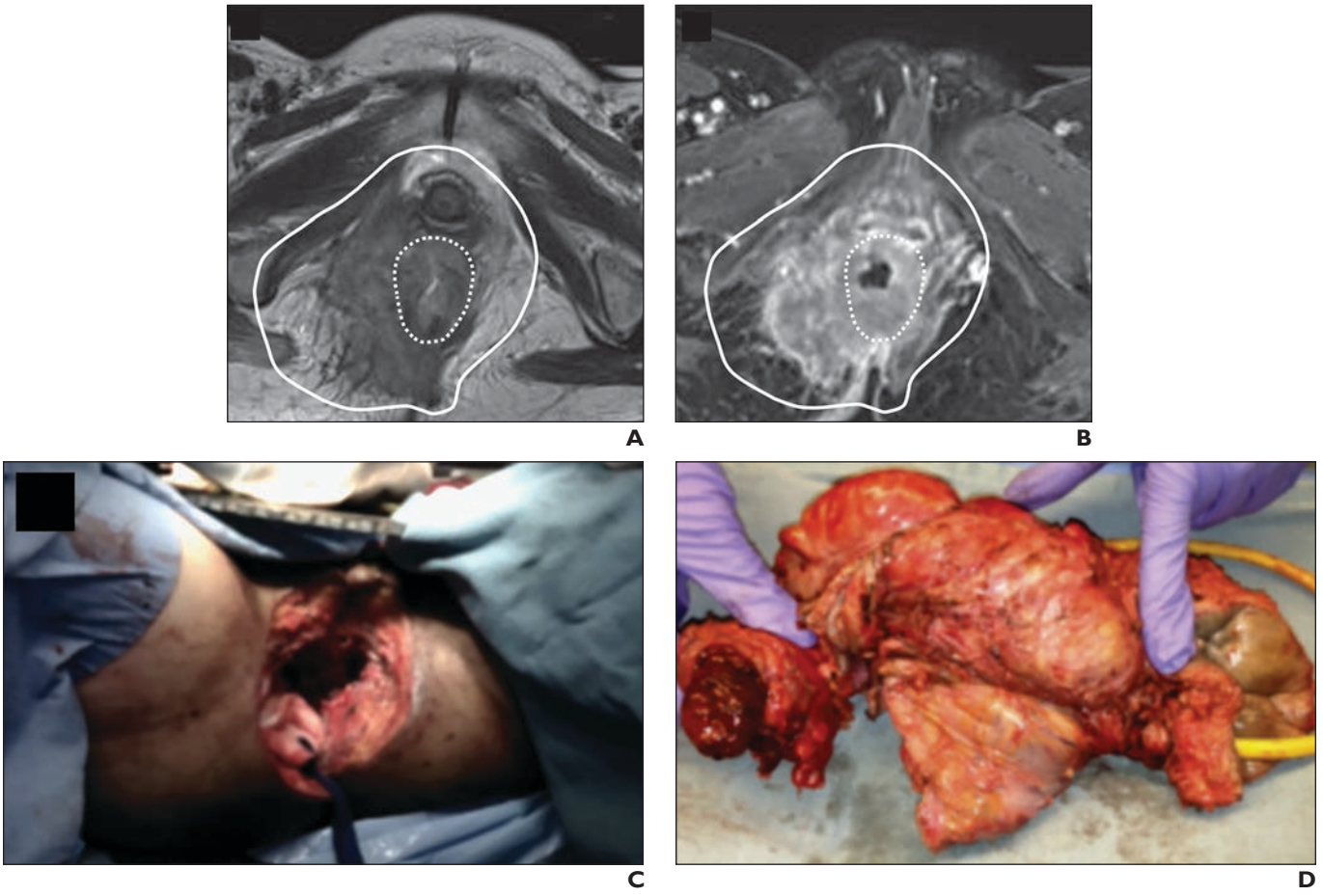


Fig. 7—Low rectal cancer in 63-year-old woman.
A and **B,** Axial T2-weighted (**A**) and contrast-enhanced T1-weighted (**B**) images depict large locally advanced low rectal cancer invading sphincter complex, extending laterally to right ischiorectal fossa and right obturator externus muscle, and invading anterior vagina. In this patient, conventional abdominoperineal resection (*dotted line*) would result in positive margin. Wide abdominoperineal excision and pelvic exenteration (*solid line*) were performed on basis of MRI findings.
C and **D,** Intraoperative photograph of surgical field (**C**) and photograph of specimen (**D**). Negative margins were obtained at histology. (Courtesy of Quereshy F, University of Toronto, Toronto, ON, Canada)

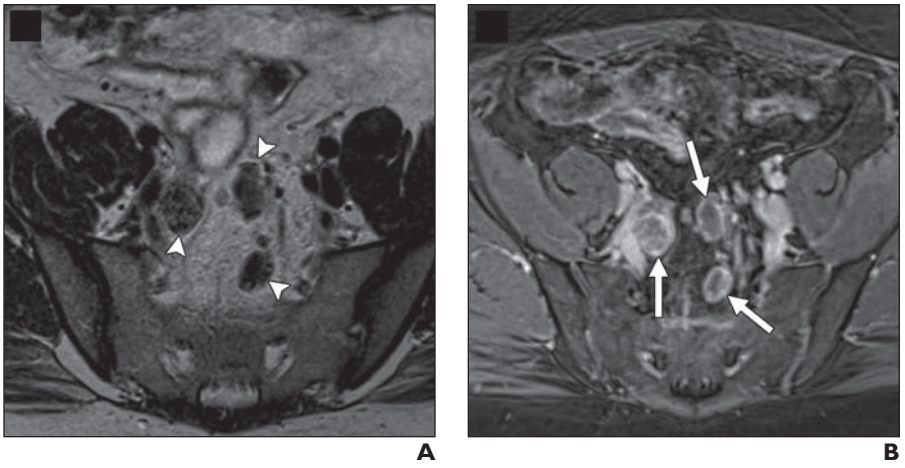


Fig. 8—Malignant pelvic lymphadenopathy with rectal cancer in 71-year-old man. (Reprinted from [24] with permission: Furey E, Jhaveri KS. MRI in rectal cancer. *Magn Reson Imaging Clin N Am* 2014; 22:165–190, v–vi)
A, Axial T2-weighted image shows three heterogeneous enlarged lymph nodes in upper mesorectum and right obturator region (*arrowheads*).
B, Involved nodes shows heterogeneous enhancement (*arrows*) on contrast-enhanced T1-weighted image.

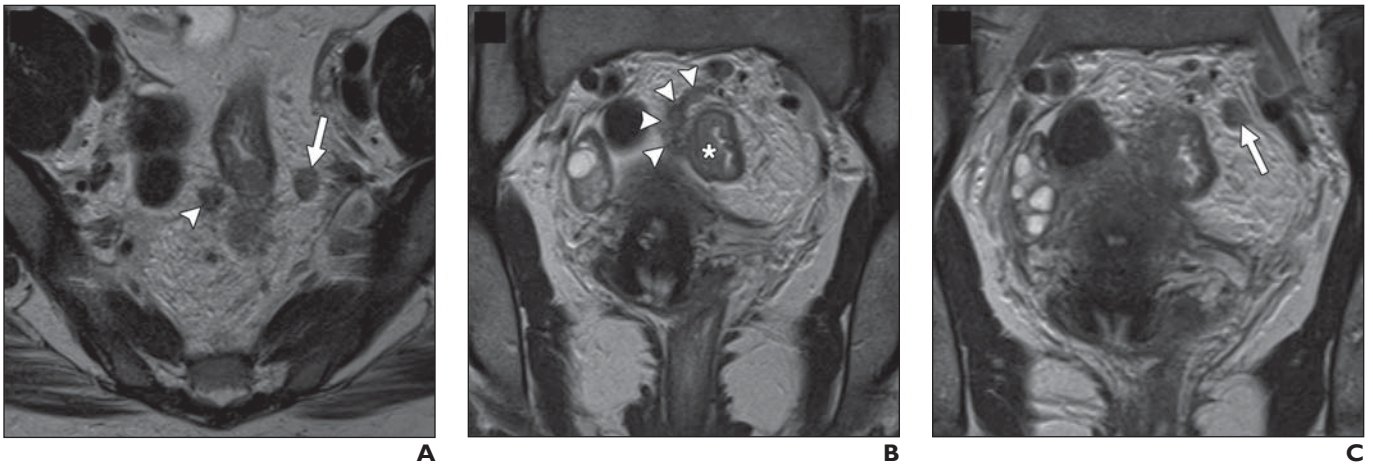


Fig. 9—Extramural vascular invasion (EMVI) versus lymph nodes in 40-year-old woman with midrectal cancer.
A, On axial T2-weighted image, two oval nodules suggestive of mesorectal nodes are evident on right (*arrowhead*) at 9-o'clock position and left (*arrow*) at 3-o'clock position of rectum.
B, Coronal T2-weighted image of right-side lesion shows irregularly expanded vessel with heterogeneous tumor signal intensity (*arrowheads*) in vicinity of rectal tumor (*asterisk*) indicative of EMVI.
C, Coronal T2-weighted image of left-side lesion (*arrow*) shows that lesion remains oval in shape, which suggests that lesion is metastatic mesorectal lymph node.

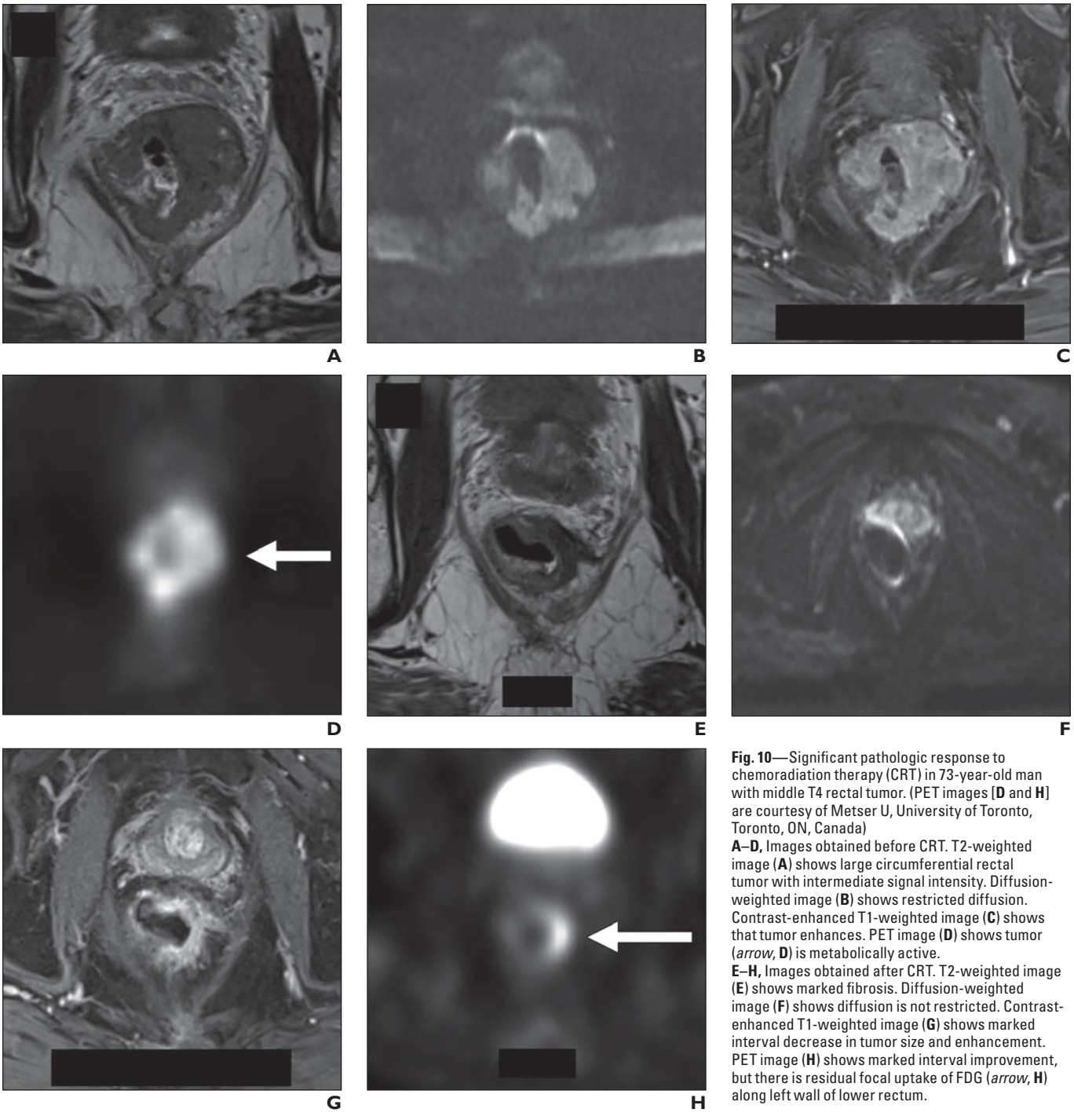


Fig. 10—Significant pathologic response to chemoradiation therapy (CRT) in 73-year-old man with middle T4 rectal tumor. (PET images [**D** and **H**] are courtesy of Metser U, University of Toronto, Toronto, ON, Canada)
A–D, Images obtained before CRT. T2-weighted image (**A**) shows large circumferential rectal tumor with intermediate signal intensity. Diffusion-weighted image (**B**) shows restricted diffusion. Contrast-enhanced T1-weighted image (**C**) shows that tumor enhances. PET image (**D**) shows tumor (*arrow*, **D**) is metabolically active.
E–H, Images obtained after CRT. T2-weighted image (**E**) shows marked fibrosis. Diffusion-weighted image (**F**) shows diffusion is not restricted. Contrast-enhanced T1-weighted image (**G**) shows marked interval decrease in tumor size and enhancement. PET image (**H**) shows marked interval improvement, but there is residual focal uptake of FDG (*arrow*, **H**) along left wall of lower rectum.