# Optimization of MR Imaging for Pretreatment Evaluation of Patients with Endometrial and Cervical Cancer[1]

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Endometrial and cervical cancer are the most common gynecologic malignancies in the world. Accurate staging of cervical and endometrial cancer is essential to determine the correct treatment approach. The current International Federation of Gynecology and Obstetrics (FIGO) staging system does not include modern imaging modalities. However, magnetic resonance (MR) imaging has proved to be the most accurate noninvasive modality for staging endometrial and cervical carcinomas and often helps with risk stratification and making treatment decisions. Multiparametric MR imaging is increasingly being used to evaluate the female pelvis, an approach that combines anatomic T2-weighted imaging with functional imaging (ie, dynamic contrast material–enhanced and diffusion-weighted imaging). MR imaging helps guide treatment decisions by depicting the depth of myometrial invasion and cervical stromal involvement in patients with endometrial cancer and tumor size and parametrial invasion in those with cervical cancer. However, its accuracy for local staging depends on technique and image quality, namely thin-section high-resolution multiplanar T2-weighted imaging with simple modifications, such as double oblique T2-weighting supplemented by diffusion weighting and contrast enhancement.



**Abbreviations:** FOV = field of view, FRFSE = fast relaxation fast spin echo, SNR = signal-to-noise ratio, 3D = three-dimensional

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## SA-CME LEARNING OBJECTIVES

*After completing this journal-based SA-CME activity, participants will be able to:*

- List the key FIGO and MR imaging staging criteria for endometrial and cervical cancer.
- Describe the most important prognostic factors for patients with endometrial and cervical cancer.
- Discuss the role of high-resolution MR imaging and its modifications in the staging of endometrial and cervical cancer.

*See www.rsna.org/education/search/RG.*

## TEACHING POINTS

*See last page*

**Table 1: Revised 2009 FIGO Staging System for Endometrial Carcinoma**

| Stage | Description |
|---|---|
| I | Tumor confined to the corpus uteri |
| IA | No or less than one-half of myometrial invasion |
| IB | Invasion up to or more than one-half of the myometrium |
| II | Tumor invades cervical stroma but does not extend beyond the uterus |
| III | Local or regional spread of tumor |
| IIIA | Invasion of the serosa or adnexa |
| IIIB | Vaginal or parametrial involvement |
| IIIC | Metastases to the pelvic or paraaortic lymph nodes |
| IIIC1 | Metastases to the pelvic lymph nodes |
| IIIC2 | Metastases to the paraaortic lymph nodes, with or without pelvic lymph node involvement |
| IV | Invasion of bladder or bowel mucosa or distant metastases present |
| IVA | Invasion of bladder or bowel mucosa |
| IVB | Distant metastases, including intraabdominal or inguinal lymph nodes |

Source.—Reference 3.

## Introduction

Endometrial carcinoma is the fourth most common cancer among women and the most common cancer of the female reproductive tract, with an estimated 49,560 new diagnoses and 8190 deaths in the United States in 2013 (1). The average age at the time of diagnosis is 61 years (1). The increasing incidence observed in recent years is thought to result from both higher life expectancy and rising rates of obesity. Cervical carcinoma is the third most common gynecologic malignancy, with 12,340 new cases and 4030 deaths in 2013 (1). Its average age at onset is 48 years (1). The widespread use of screening with the Papanicolaou smear and effective treatment of carcinoma in situ have led to a significant decline in cervical cancer in the developed world (2).

The International Federation of Gynecology and Obstetrics (FIGO) staging of endometrial cancer is surgical and consists of hysterectomy, bilateral salpingo-oophorectomy, node dissection, peritoneal washing, and omental biopsy (Table 1) (3). The clinical management of endometrial cancer is distinct from the FIGO staging requirements. Patients who present with early-stage disease with a low or intermediate risk—including stage IA grades 1, 2, and 3 and stage IB grades 1 and 2 with endometrioid histologic characteristics—may be appropriately treated with minimally invasive laparoscopic hysterectomy and bilateral salpingo-oophorectomy, an approach that decreases morbidity and hospital stays and has comparable outcomes in this group compared with more extensive surgical resection, which should be reserved for high-risk patients with stage IB grade 3 endometrioid disease, stage II and higher, and all grades of nonendometrioid disease (4–7). However, effective implementation of this treatment approach relies heavily on accurate preoperative staging. Magnetic resonance (MR) imaging, particularly the multiparametric approach, has been shown to reliably depict the key prognostic factors for endometrial cancer: depth of myometrial invasion and cervical stromal involvement (7–11). Although it is not part of the FIGO criteria, staging MR imaging is recommended by the National Cancer Institute of France, the European Society of Radiology Guidelines, and the Royal College of Radiologists (12–14).

Assessing lymph node involvement in patients with endometrial cancer on the basis of size criteria has substantial limitations. However, the incidence of nodal involvement correlates with the depth of myometrial invasion and cervical stromal involvement; consequently, these characteristics may be used as surrogates to determine whether lymph node dissection is necessary (13,15,16). The incidence of lymph node metastasis increases from 3% when the depth of tumor invasion is less than 50% of myometrial thickness to 46% when more than 50% of myometrial thickness is involved (5,17,18).

The role of imaging in endometrial cancer staging potentially received a boost when the FIGO staging system was modified in 2009 (3). The new staging system combines superficial invasion (less than 50% of myometrial thickness) and disease that is confined to the endometrial cavity as stage IA, whereas tumors that invade the outer one-half of the myometrium (greater than 50% thickness) are classified as stage IB. In addition, the definition of stage II changed with the removal of cervical mucosal involvement as a determinate of upstaging, with only cervical stromal invasion now used to define stage II tumors. Distinguishing disease that is confined to the endometrial cavity from superficial myometrial invasion and defining cervical mucosal involvement, which were part of the previous FIGO staging system, was a limitation of imaging; eliminating these categories could improve the accuracy of staging MR imaging in patients with endometrial cancer (19).

Cervical cancer is the only gynecologic malignancy that is still clinically staged according to the revised 2009 FIGO classification system (Table 2)

(20). However, the committee encourages the use of imaging, if available, because clinical staging is inaccurate in 22%–75% of patients (21). The use of MR imaging enables patients to be more appropriately triaged for hysterectomy, if the tumor is confined to the cervix and smaller than 4 cm, or chemoradiation therapy, if the tumor size exceeds 4 cm or parametrial invasion is present. Although recent multi-institutional trials raised concerns about the accuracy of cross-sectional imaging in staging early (lower than stage IIB) cervical cancer, MR imaging remains the best modality for assessing tumor size, with a high negative predictive value for excluding parametrial invasion (22–26).

Improving the accuracy of MR imaging depends on the use of an appropriate MR imaging technique. Recent publications underscore the value of multiparametric MR imaging that combines sagittal and axial oblique T2-weighted, dynamic contrast-enhanced, and diffusion-weighted imaging sequences for staging and treatment stratification in patients with gynecologic malignancies (7,27). In this article, we review optimized MR imaging protocols that incorporate high-resolution T2-weighted sequences, with an emphasis on the importance of obtaining good-quality multiplanar, dynamic contrast-enhanced, and diffusion-weighted images.

## Multiparametric MR Imaging of Endometrial Cancer

The combination of T2-weighted and dynamic contrast-enhanced MR images offers high accuracy for staging endometrial cancer in the range of 83%–91%, with only a few dissenting papers reporting that the use of contrast enhancement offers no added benefit (2,9,28–31). More recent studies reported that axial oblique fused T2- and diffusion-weighted images have high accuracy in assessing the depth of myometrial invasion, with some papers reporting not only superior accuracy compared with dynamic contrast-enhanced MR imaging, but also higher interobserver agreement (32–34).

A combination of all three sequences may represent the most comprehensive approach to preoperative staging of endometrial cancer (7,27). An important part of the multiparametric approach is the acquisition of good-quality multiplanar images, particularly in two planes orthogonal to the tumor with each sequence, if possible, and definitely with the T2-weighted and contrast-enhanced T1-weighted sequences. In addition, orthogonal T2-weighted, dynamic contrast-enhanced, and diffusion-weighted images should coregister by section location to enable correlation of findings, which improves staging accuracy (4).

**Table 2: New FIGO Classification for Cervical Carcinoma**

| Stage | Desciption |
|---|---|
| I | Carcinoma strictly confined to the cervix, excluding extension to the corpus |
| IA | Invasive carcinoma that may be diagnosed only at microscopy, with deepest invasion ≤5 mm and largest extension ≤≥7 mm |
| IA1 | Measured stromal invasion of ≤3.0 mm in depth and extension of ≤7.0 mm |
| IA2 | Measured stromal invasion between 3.0 mm and 5.0 mm with extension ≤7.0 mm |
| IB | Clinically visible lesion that is limited to the cervix uteri or a preclinical cancer with a stage higher than IA |
| IB1 | Clinically visible lesion ≤4.0 cm in greatest dimension |
| IB2 | Clinically visible lesion >4.0 cm in greatest dimension |
| II | Cervical carcinoma extends beyond the uterus but not to the pelvic wall or the lower one-third of the vagina |
| IIA | No parametrial invasion is present |
| IIA1 | Clinically visible lesion ≤4.0 cm in greatest dimension |
| IIA2 | Clinically visible lesion >4.0 cm in greatest dimension |
| IIB | Obvious parametrial invasion is present |
| III | Tumor extends to the pelvic wall, involves the lower one-third of the vagina, or causes hydronephrosis or a nonfunctioning kidney |
| IIIA | Tumor involves the lower one-third of the vagina with no extension to the pelvic wall |
| IIIB | Extension to the pelvic wall or hydronephrosis or a nonfunctioning kidney is present |
| IV | Extension beyond the true pelvis or involvement of the bladder or rectal mucosa (biopsy proved)* |
| IVA | Spread to adjacent organs |
| IVB | Spread to distant organs |

Source.—Reference 20.
*The presence of bullous edema does not qualify for a classification of stage IV disease.

### High-Resolution Multiplanar T2-weighted MR Imaging

T2-weighted MR imaging is the key sequence for evaluating myometrial invasion because it depicts the uterine zonal anatomy, with the intermediate-signal-intensity tumor well delineated against the low-signal-intensity junctional zone (Fig 1) (7–9,11). However, its utility may be limited in patients who are postmenopausal

Teaching Point

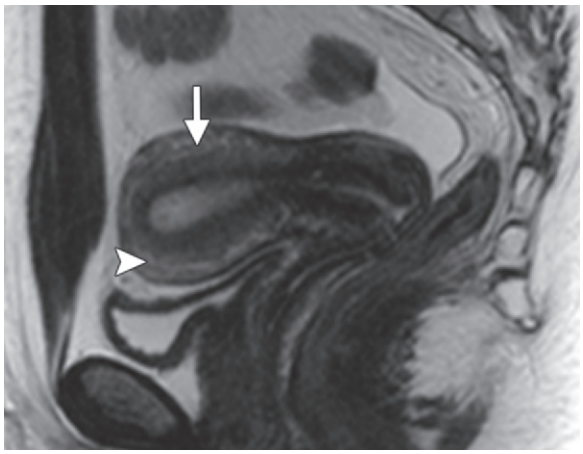
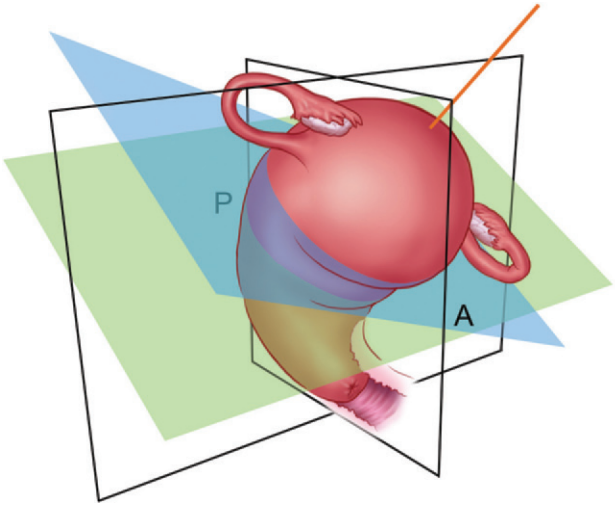


**Figure 1.** Normal uterine zonal anatomy. Sagittal high-resolution T2-weighted FRFSE MR image shows the normal uterine zonal anatomy. The high-signal-intensity endometrium is surrounded by the homogeneous low-signal-intensity junctional zone (arrow), which is continuous with the fibrous cervical stroma. The myometrium (arrowhead) has intermediate signal intensity and is contiguous with the outer interstitial cervical stroma.



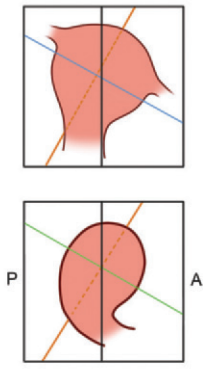






**Figure 2.** The double oblique technique. Illustration shows a uterus that is anteriorly rotated in the sagittal plane (anteverted) and laterally tilted to the left in the coronal plane. The double oblique sequence is performed by angling images anteriorly in the sagittal plane (green line) and laterally in the coronal plane (blue line), which creates true oblique images along the true axis of the uterus (orange line). *A* = anterior, *P* = posterior.

because, in these patients, the zonal anatomy of the uterus is less defined or the tumor may be isointense relative to the myometrium.

***Technique.***—The use of thin-section (3-mm) axial oblique and sagittal T2-weighted imaging (field of view [FOV], 20–22 cm) is well established for staging endometrial cancer (27). Our suggested modification to the imaging protocol is to obtain high-resolution T2-weighted fast relaxation fast spin-echo (FRFSE) images in three planes: sagittal, coronal, and axial oblique. In addition, because the position of the uterus is notoriously variable, obtaining an axial oblique image on the basis of only the sagittal images may not provide an orthogonal view of the tumor. Thus, obtaining an additional sequence may be useful when the uterus is tilted to the left or right of the midline. In such cases, axial oblique T2-weighted images that angle off both the sagittal and coronal planes create a "true axial oblique" plane that is correctly positioned along the true axis of the uterus. This method is referred to as a "double oblique" sequence because it is oblique in two planes (sagittal and coronal) (Fig 2). High-resolution double oblique images provide a true orthogonal view of the uterus, with the potential to avoid volume averaging, and they improve assessment of myometrial invasion (Fig 3).

Teaching Point

To ensure good spatial resolution and signal-to-noise ratio (SNR), images should be acquired with a surface coil appropriately centered over the uterus and a 20–24-cm FOV with 3-mm contiguous cuts. The FOV should be adjusted to ensure appropriate SNR and increased if necessary; this step may double the SNR (Fig 4). It is also valuable to have the patient fast 4–6 hours and empty the bladder before imaging to reduce motion. Antiperistaltic agents, such as hyoscine butylbromide and glucagon, are used in many centers to reduce motion artifacts from bowel peristalsis (27). The phase and frequency directions may also be adjusted to avoid motion artifacts from bowel loops or the bladder wall. In general, use of a wide anterior saturation fat suppression pulse may eliminate motion artifacts from the anterior abdominal wall (Fig 5).

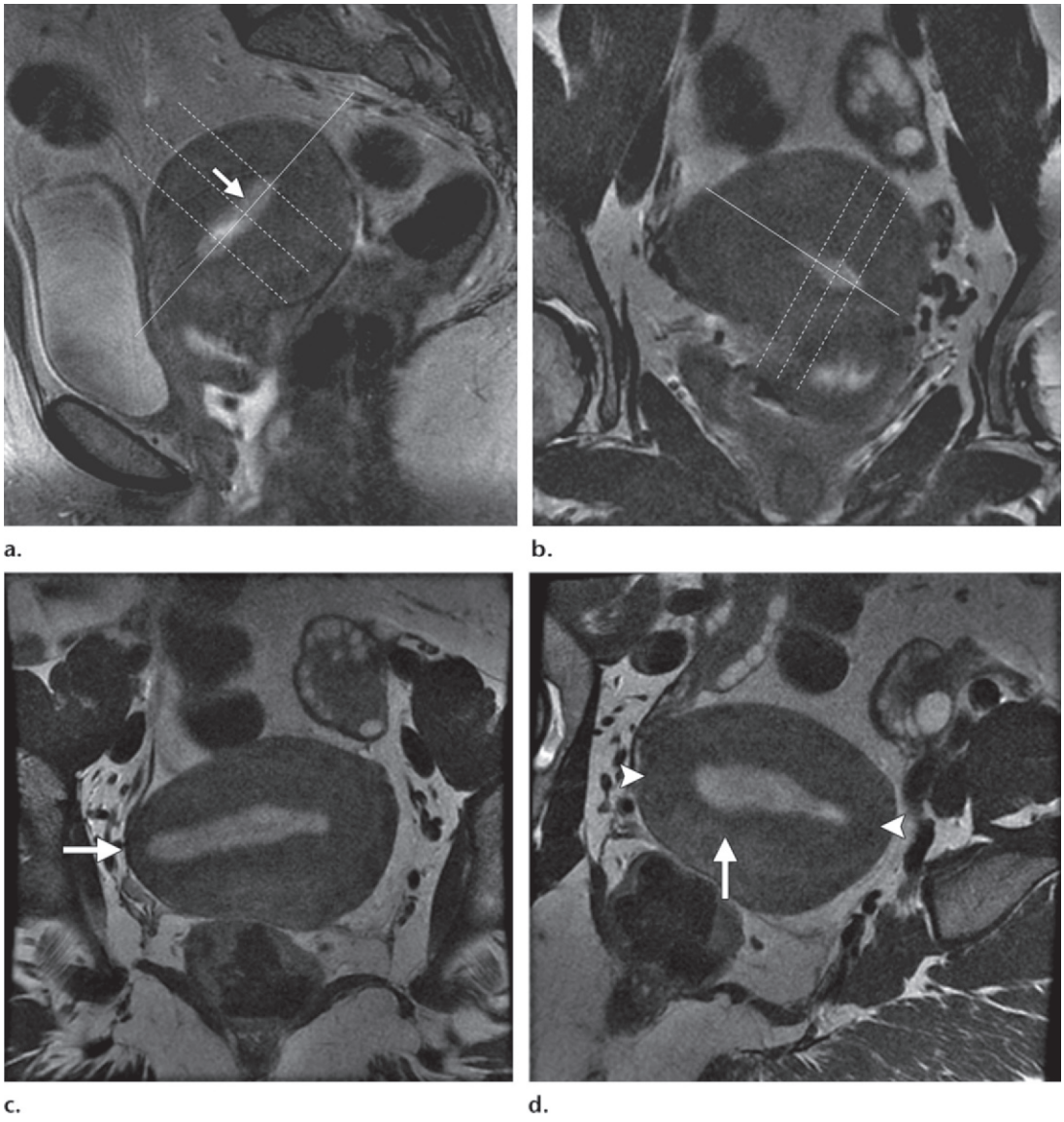



**Figure 3.** Double oblique technique in a patient with endometrial cancer. **(a)** High-resolution sagittal T2-weighted FRFSE MR image shows the correct plane for prescribing the orthogonal axial images perpendicular to the endometrial cavity in patients with endometrial carcinoma. Solid line and arrow = long axis of the uterus, dashed lines = plane of acquisition for routine axial oblique sections. **(b)** Coronal high-resolution FRFSE T2-weighted MR image shows that the body of the uterus is deviated to the right. The second oblique plane is prescribed perpendicular to the axis of the uterus in the coronal plane. The axis of the endometrial cavity in the coronal plane (solid line) and the acquisition plane of the oblique axial images (dashed lines) are seen. The combination of both acquisitions prescribed along the long axis of the uterus in the sagittal and coronal planes forms the double oblique axial image. **(c)** Axial oblique high-resolution T2-weighted FRFSE MR image shows apparent thinning of the right myometrium (arrow), which may be mistaken for myometrial invasion. **(d)** Double oblique high-resolution T2-weighted FRFSE MR image prescribed with both the sagittal and coronal planes is more appropriately angled along the true axis of the uterus and shows the thickness of the myometrium to be symmetric (arrowheads). Subtle superficial invasion of the inner myometrium is seen along the anterior wall (arrow). High-resolution double oblique images are particularly useful when lateral deviation of the uterus is seen in the coronal plane and minimize problems with volume averaging that result from the position of the uterus within the pelvis, which may lead to erroneous interpretations of myometrial invasion.

Teaching Point

The advantage of multiplanar high-resolution MR imaging for tumor staging is its improved spatial resolution and depiction of disease extent in more than one plane, which are essential for accurate staging (Fig 6) (4,33).

Although T2-weighted imaging is essential, it often proves inadequate because of its poor tumor-to-myometrium contrast and poor definition of the junctional zone, particularly in patients who are postmenopausal or who have adenomyosis or

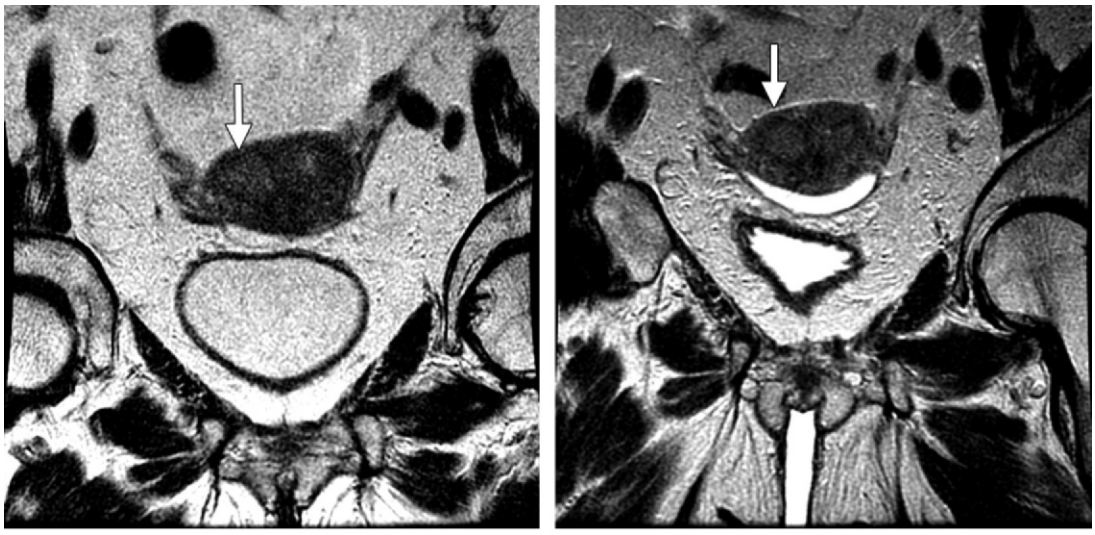


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**Figure 4.** Poor SNR may be improved by increasing FOV. **(a)** Coronal high-resolution T2-weighted FRFSE MR image obtained at the level of the pelvis (FOV, 18 cm) poorly depicts an endometrial tumor (arrow), a result of poor SNR. **(b)** Coronal high-resolution T2-weighted FRFSE MR image obtained with a larger FOV (20 cm) shows the tumor expanding the endometrial cavity (arrow). This simple step doubles the SNR.

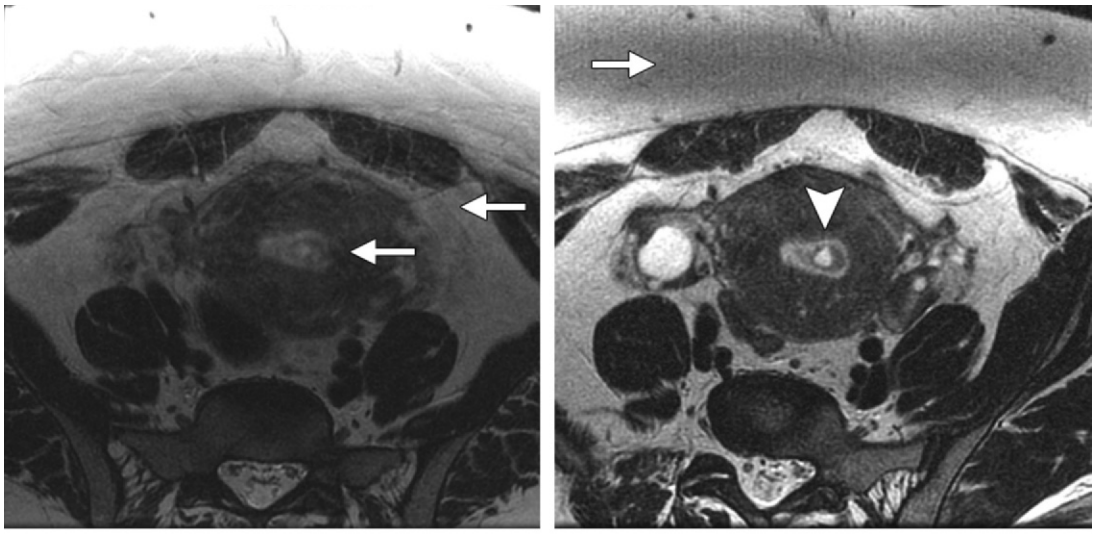

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**Figure 5.** Use of an anterior saturation band and adjusting matrix size to eliminate artifacts and improve SNR. **(a)** Axial oblique high-resolution T2-weighted MR image obtained at the level of the uterus with a 320 × 256 matrix shows motion artifacts (arrows) and poor SNR, which limit evaluation of the endometrial-myometrial interface. **(b)** Axial oblique high-resolution T2-weighted MR image obtained at the level of the uterus with a 256 × 256 matrix shows a polypoid mass (arrowhead) that is confined to the endometrial cavity. Placement of an anterior saturation band (arrow) eliminates motion artifacts from anterior abdominal wall fat, and the use of a smaller matrix increases SNR and improves image quality

leiomyomas, which compromise staging (Fig 7). Occasionally, dynamic contrast-enhanced and diffusion-weighted imaging may help overcome these potential pitfalls. The relative merits of T2-weighted and dynamic contrast-enhanced MR imaging appear to be related to menopausal status: T2-weighted imaging has greater accuracy in those who are premenopausal, whereas dynamic contrast-enhanced MR imaging is more accurate in those who are postmenopausal (35).

## Dynamic Contrast-enhanced MR Imaging

With the exception of a few dissenting reports, it is widely accepted that dynamic contrast-enhanced MR imaging improves accuracy of tumor staging in patients with endometrial cancer.

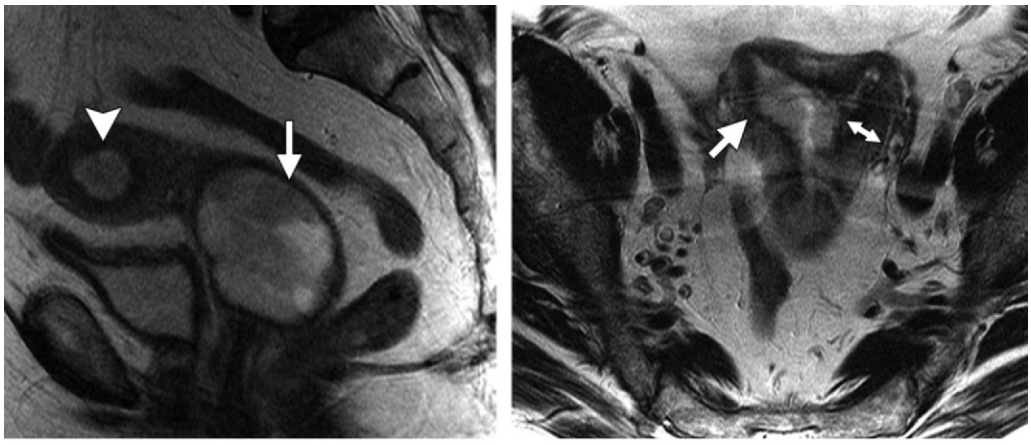

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**Figure 6.** Use of two orthogonal planes along the long axis of the tumor. **(a)** Sagittal high-resolution T2-weighted FRFSE MR image shows a polypoid mass expanding the endometrial cavity (arrowhead) and extending into and expanding the endocervical canal (arrow). It is difficult to determine whether myometrial invasion is present. **(b)** Axial high-resolution T2-weighted FRFSE MR image obtained along the coronal plane of the uterus and orthogonal to the sagittal images shows broad-based myometrial invasion along the right lateral wall (arrow) that is limited to the inner one-half of the myometrium. The depth of myometrial invasion was assessed on the basis of the thickness of the contralateral wall (double headed arrow), a finding that was confirmed at pathologic analysis.

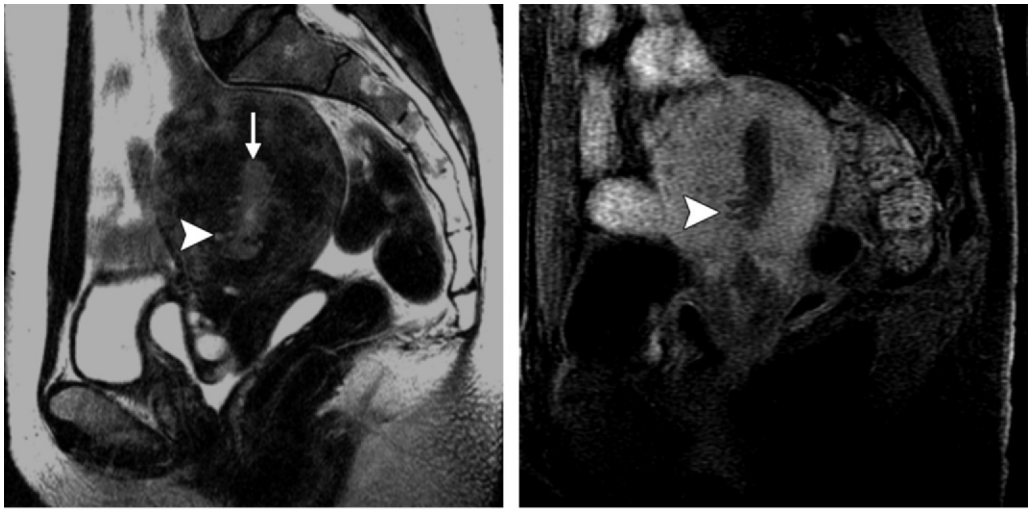

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**Figure 7.** Adenomyosis in a patient with myometrial invasion. **(a)** Sagittal high-resolution T2-weighted FRFSE MR image shows widening of the junctional zone, small punctate foci of hyperintensity, and striations in the anterior myometrium, findings indicative of adenomyosis (arrowhead). A tumor is also seen in the endometrial cavity (arrow). **(b)** Sagittal contrast-enhanced T1-weighted 3D MR image shows defects in the anterior myometrium (arrowhead) that correspond to the findings of adenomyosis on the sagittal T2-weighted image. In this case, the signal intensity on the T2-weighted image and the sharply marginated appearance on the contrast-enhanced image suggest the presence of adenomyosis in the anterior inner myometrium rather than tumor infiltration, but tumor infiltration cannot be excluded with certainty. The presence of adenomyosis limits the ability to accurately assess myometrial invasion at either sequence.

This improved accuracy is, essentially, a result of the improved tumor-to-myometrial contrast that is generally seen on delayed (2–4 minutes after administration of contrast material) images, with most endometrial tumors appearing hypointense against the enhancing myometrium (Fig 8). An additional benefit of contrast-enhanced imaging is that small tumors that may be difficult to define at T2-weighted imaging may appear hypervascular in the early arterial phase and in patients with loss of the junctional zone or adenomyosis. Contrast-enhanced images may also depict the

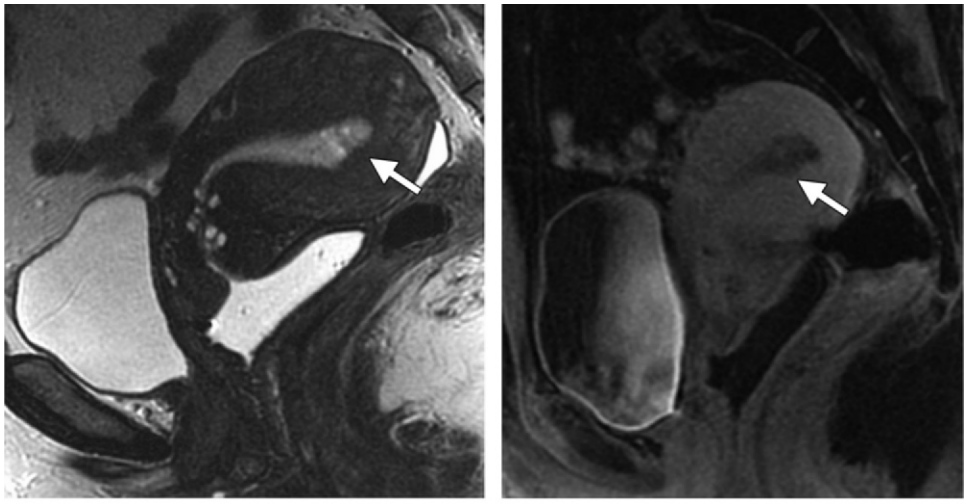

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**Figure 8.** Value of contrast-enhanced T1-weighted images in assessing myometrial invasion. **(a)** Sagittal high-resolution T2-weighted FRFSE MR image shows a small endometrial mass in the uterine fundus (arrow). **(b)** Sagittal dynamic contrast-enhanced T1-weighted 3D FSPGR MR image obtained in the delayed phase (2–4 minutes after administration of contrast material) shows myometrial invasion along the posterior uterine wall (arrow) that is confined to the inner myometrium. Use of delayed contrast enhancement optimizes contrast between the myometrium and tumor.

depth of myometrial invasion, and the presence of an intact enhancing cervical mucosa excludes cervical stromal invasion (27,33). A limitation of dynamic contrast-enhanced MR imaging is that some tumors may be isointense relative to the myometrium in the equilibrium phase (2 min after administration of contrast material), which negates the benefits of this sequence.

The efficacy of dynamic contrast-enhanced MR imaging for tumor staging relies on obtaining images in two orthogonal planes: sagittal and axial oblique (33). Most commonly, dynamic contrast-enhanced T1-weighted fat-suppressed three-dimensional (3D) fast spoiled gradient echo images (FSPGR) images are acquired in the sagittal plane at 30, 60, and 120 seconds after administration of contrast material or by continuously imaging at the level of the uterus for 2 minutes. Next, delayed (3–4 minutes after administration of contrast material) axial oblique T1-weighted fat-suppressed 3D images are acquired along the axis of the uterus, preferably with the same section positions as those used to obtain axial oblique T2-weighted images (Fig 9).

## Diffusion-weighted Imaging

Diffusion-weighted imaging is a functional imaging technique whose contrast derives from the differences in restriction of motion of water molecules. In recent years, the clinical use of diffusion-weighted imaging in patients with gynecologic malignancies has been steadily increasing (36–39). Studies have shown that endometrial cancer has a significantly lower apparent diffusion coefficient (ADC) value ($0.86–0.98 \times 10^{-3}$ mm$^2$/sec) than does normal endometrium ($1.28–1.65 \times 10^{-3}$ mm$^2$/sec) and that higher-grade endometrial cancers tend to have lower ADC values than do more well-differentiated tumors (36,37,40,41). These distinct ADC values may help localize endometrial malignancies that are located in the midst of normal endometrium, which facilitates tumor staging.

Recent reports on the efficacy of diffusion-weighted imaging in tumor staging concluded that diffusion-weighted imaging with a relatively high $b$ value ($b$ = 1000 sec/mm$^2$) combined with T2-weighted imaging accurately depicts myometrial invasion and reportedly improves the accuracy of T2-weighted and dynamic contrast-enhanced MR imaging (32). The effect of this technique is particularly evident in the presence of a tumor that is isointense relative to the myometrium on dynamic contrast-enhanced MR images and when intravenous contrast material may not be used.

Diffusion-weighted images should be obtained with variable $b$ values ranging, preferably, from 50 sec/mm$^2$ to 500–1000 sec/mm$^2$ in the pelvis. Ideally, images should be acquired in the same plane and with a comparable FOV as those used to obtain axial oblique T2-weighted and dynamic contrast-enhanced images and then fused. If images may not be fused, the section locations should be coregistered at all three sequences to permit correlation (Fig 10). During image interpretation, it is important that diffusion-weighted images always

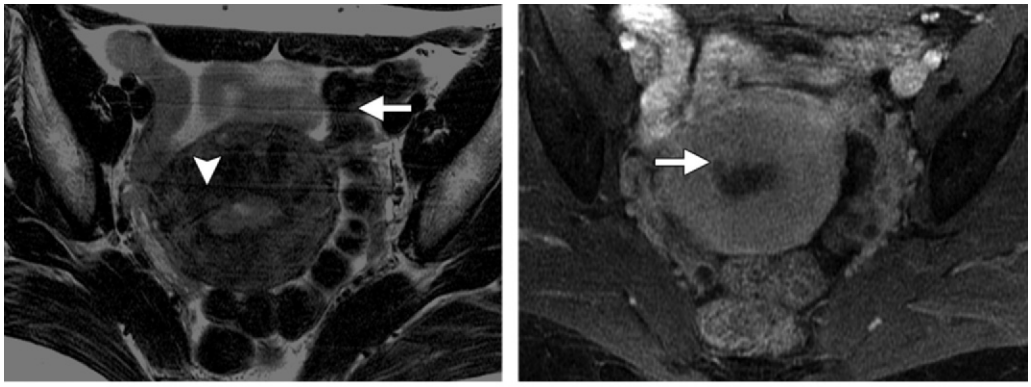

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**Figure 9.** Coregistration of high-resolution T2-weighted FRFSE and dynamic contrast-enhanced MR imaging with the same section positions. **(a)** Axial high-resolution T2-weighted MR image obtained at the level of the uterus shows a hyperintense tumor in the endometrial cavity with a subtle signal abnormality in the anterior myometrium (arrowhead), a finding that may indicate invasion. Motion artifact (arrow) is also present, which limits evaluation. Note that an anterior saturation pulse was not placed over the anterior abdominal wall fat. **(b)** Axial contrast-enhanced T1-weighted 3D MR image obtained in the delayed phase shows invasion into the inner myometrium (arrow). Often, contrast-enhanced images obtained in the same plane as T2-weighted images confirm a subtle finding and provide a backup if one series is degraded by artifacts and is suboptimal for diagnostic evaluation.

be read in conjunction with ADC maps to avoid misinterpretation related to T2 shine through.

## MR Imaging of Cervical Cancer

The utility of the multiparametric approach is limited in patients with cervical cancer, and multiplanar T2-weighted imaging remains the mainstay of cancer staging. The reported accuracy of T2-weighted imaging is 83%–93% for depicting the diameter of cervical tumors and 80%–87% for assessing parametrial extension (20,25,42,43). Although this accuracy has not been reproduced in multi-institutional trials, MR imaging remains the best modality for depicting tumors and assessing tumor size, which is an important prognostic factor and determinant of treatment (Fig 11). In addition, it has a high negative predictive value for excluding parametrial invasion, the presence of which precludes surgical resection, making it a valuable tool for identifying potential candidates for surgery (22,23). High-resolution MR images obtained in multiple planes provide excellent depiction of cervical tumors and their relationship with the bladder, rectosigmoid, and pelvic sidewall, which affects staging and chemoradiation therapy planning (Fig 12).

Axial oblique and sagittal high-resolution T2-weighted images are widely accepted as being essential for evaluating cervical cancer (27). Previous studies have shown that, even if they are obtained with a body coil, 3-mm-thick axial oblique T2-weighted images improve assessment of parametrial invasion over routine axial T2-weighted images (44). In our experience, the addition of coronal and double oblique high resolution T2-weighted images may provide added benefits in certain circumstances.

Sagittal and axial oblique high-resolution T2-weighted imaging is the key sequence for depicting cervical cancer (Fig 13). However, when the cervix angles to the left or right as defined in the coronal plane, its utility may be limited by volume averaging. In this situation, use of a double oblique angle that is based on sagittal and coronal T2-weighted images is useful because it enables images to be acquired along the axis of the cervix and clearly defines the intact "donut" of the cervical stromal ring (Fig 14).

Dynamic contrast-enhanced MR imaging has no value in assessing parametrial invasion, but some reports have suggested that it depicts small cervical tumors, particularly in patients who may be eligible for fertility-sparing procedures. It also depicts bladder wall involvement in those with advanced disease (45).

Currently, diffusion-weighted imaging has little value in cervical cancer staging, but it has been

**Figure 11.** Value of multiplanar high-resolution MR imaging in assessing tumor size. **(a)** Axial high-resolution T2-weighted MR image obtained in a patient with a large cervical tumor shows the tumor to be 4.5 cm, an underestimation. **(b)** Sagittal high-resolution T2-weighted MR image shows the actual size of the tumor, with the largest diameter measuring 6.1 cm. Cervical tumor size should be measured in all three orthogonal planes. ▶

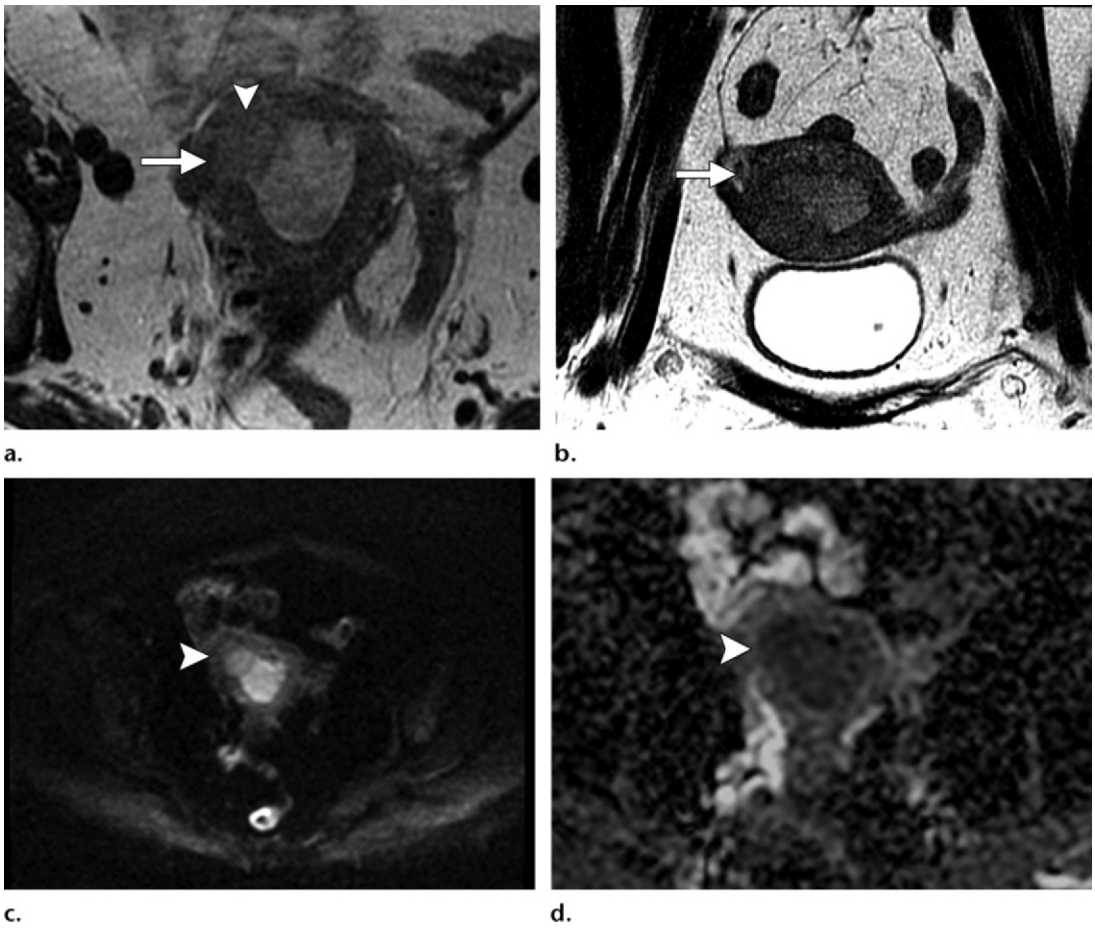
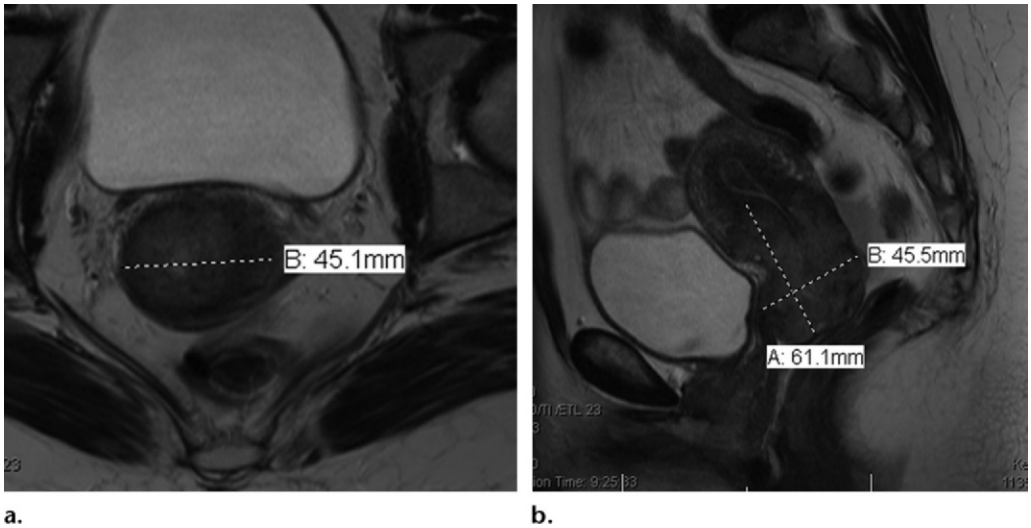
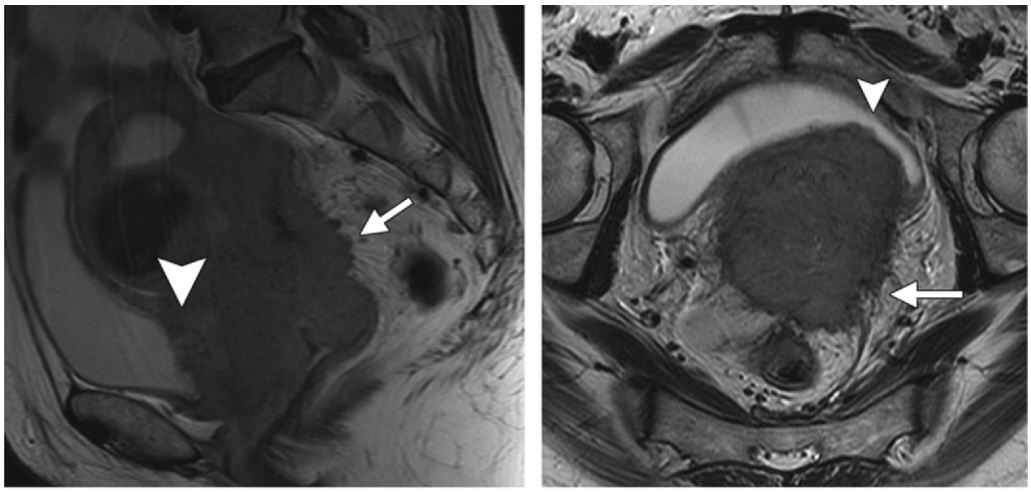


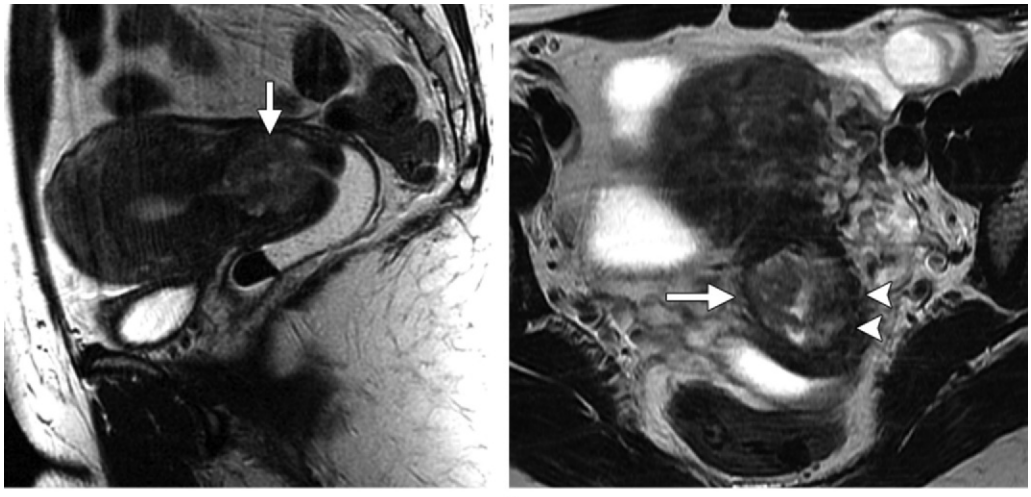
**Figure 10.** Value of diffusion-weighted images obtained in planes comparable to those used to obtain high-resolution FRFSE T2-weighted images. **(a)** Axial high-resolution T2-weighted FRFSE MR image obtained coronal to the plane of the uterus because of uterine angulation shows a tumor expanding the endometrial cavity (arrow) with possible invasion of the right myometrium (arrowhead). **(b)** Axial oblique high-resolution T2-weighted FRFSE MR image fails to adequately delineate the depth of invasion (arrow). **(c, d)** Diffusion-weighted MR image **(c)** and ADC map **(d)** obtained with comparable obliquity show restricted diffusion throughout the entire endometrium and confirm the presence of tumor infiltration into the right myometrium (arrowhead). This case illustrates the value of obtaining diffusion-weighted images in an identical imaging plane as that used to obtain T2-weighted FRFSE images to confidently assess the depth of myometrial invasion. The endometrial cavity has low ADC values, a finding compatible with tumor. Tumor occupying the entire endometrial cavity and superficial invasion of the right myometrium were confirmed at pathologic analysis.





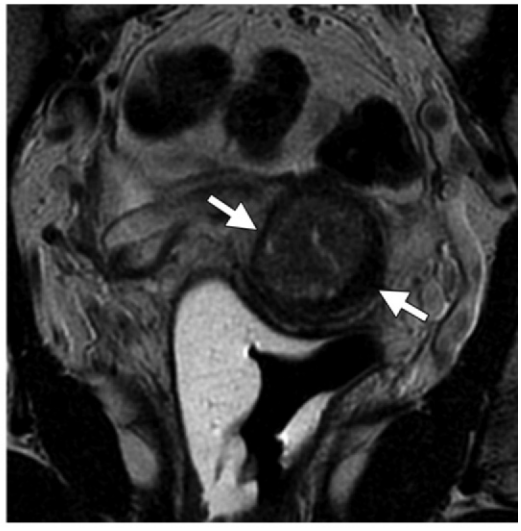
a. b.

**Figure 12.** Locally advanced cervical cancer with bladder involvement at high-resolution MR imaging. **(a)** Sagittal high-resolution T2-weighted FRFSE MR image shows a large mass replacing the entire cervix and invading the body of the uterus. Note extension of tumor into the bladder mucosa (arrowhead) and perirectal fat (arrow). **(b)** Oblique high-resolution T2-weighted FRFSE MR image shows irregular protrusions of tumor circumferentially infiltrating the parametria, a finding consistent with bilateral parametrial extension that is more prominent on the left (arrow). Note invasion of the posterior wall of the urinary bladder with mucosal involvement on the left (arrowhead).



a. b.

**Figure 13.** The value of orthogonal multiplanar high-resolution T2-weighted FRFSE sequences for evaluating cervical cancer. **(a)** Sagittal T2-weighted MR image shows a hyperintense mass (arrow), a finding indicative of high-grade cervical adenocarcinoma. **(b)** Axial T2-weighted MR image obtained coronal to the plane of the tumor poorly depicts the cervical stroma and parametrial invasion. The fibrous stroma on the right has an irregular contour (arrow), and minute interruptions of the fibrous stroma are seen at left (arrowheads), a finding indicative of deep cervical stromal invasion and possible parametrial extension. **(c)** Axial oblique high-resolution T2-weighted MR image, obtained perpendicular to the axis of the cervix at the level of possible deep cervical stromal and parametrial extension, shows an intact thin layer of preserved fibrous stroma bilaterally (arrows), indicating that the tumor is confined to the cervix.



c.

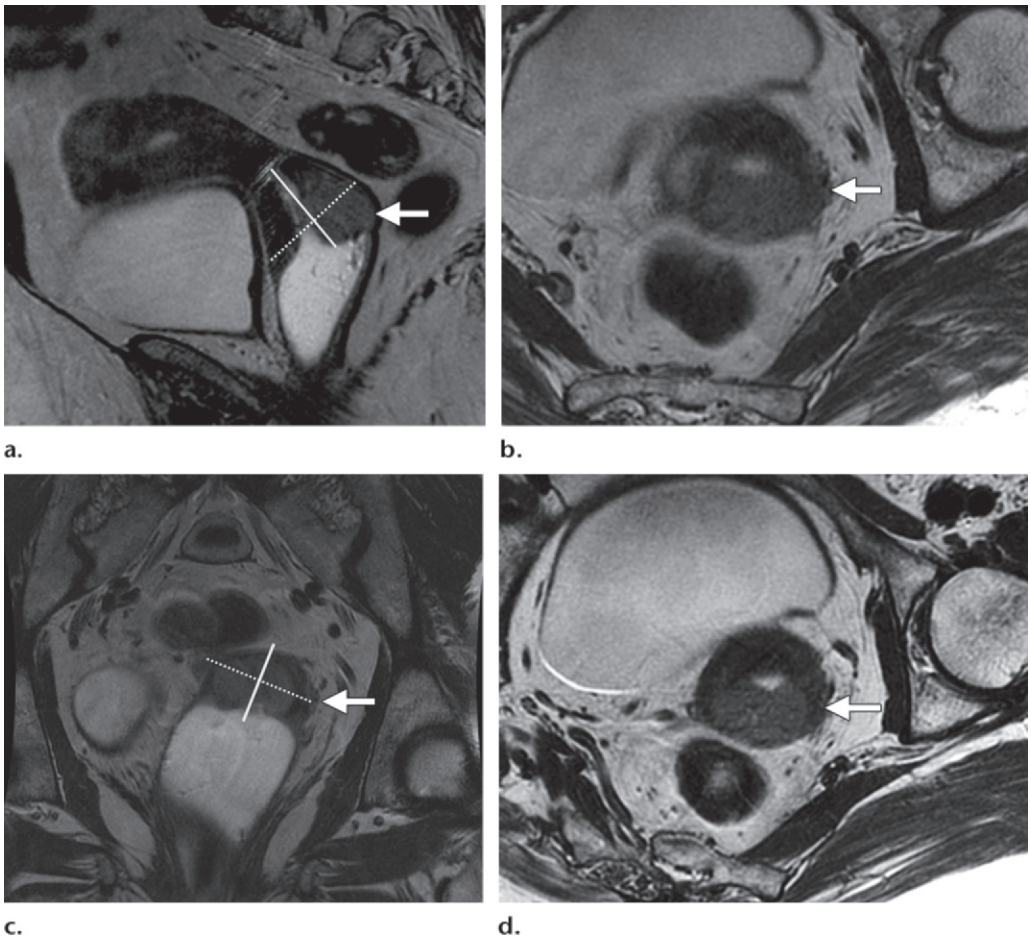



**Figure 14.** Value of double oblique high-resolution T2-weighted FRFSE MR images for depicting parametrial invasion. **(a)** Sagittal high-resolution T2-weighted FRFSE MR image shows an intermediate-signal-intensity mass in the posterior cervical lip (arrow) and the acquisition plane (dashed line) of oblique axial images, which were obtained perpendicular to the long axis of the cervix (solid line). **(b)** Axial oblique high-resolution T2-weighted FRFSE MR image obtained on the basis of sagittal T2-weighted images shows the mass in the posterior cervical lip with possible tumor infiltration into the left parametrium (arrow). **(c)** Coronal T2-weighted MR image shows the cervix, which angles to the left of the midline (arrow), and the angle of acquisition (dashed line) of the double oblique axial image perpendicular to the long axis of the laterally deviated cervix (solid line). **(d)** Double oblique T2-weighted MR image angled along the axis of the cervix on the basis of the sagittal and coronal images shows an intact cervical stroma (arrow) between the tumor and the parametrium, excluding parametrial invasion at left. Double oblique images are valuable in eliminating the effects of volume averaging.

used to localize small cervical tumors in conjunction with T2-weighted imaging. A few studies report that ADC values for cervical cancer (0.757–1.11 × $10^{-3}$ $mm^2$/sec) are substantially lower than those for a normal cervix (1.33–2.09 × $10^{-3}$ $mm^2$/sec), which could potentially play a role in diagnosing and staging cervical caner (36,46,47).

## 3D T2-weighted MR Imaging

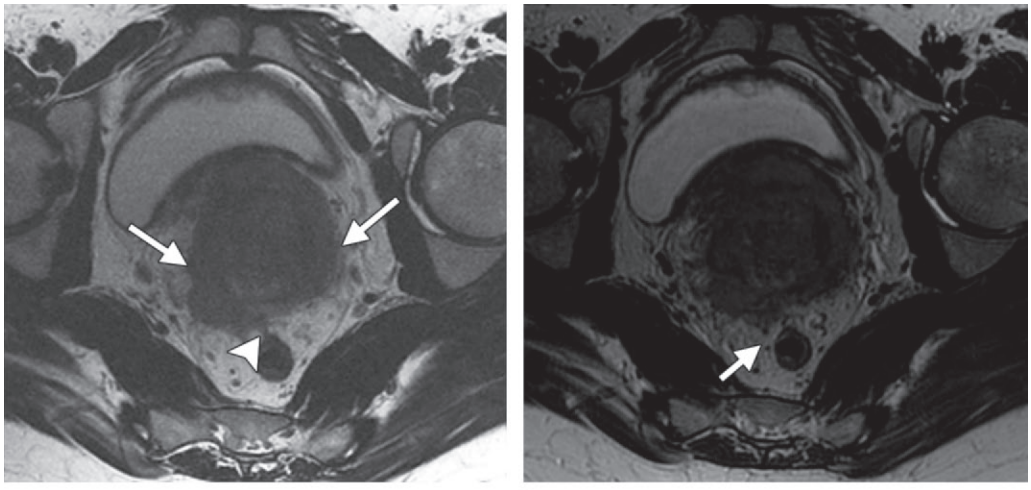
Teaching Point

The T2-weighted sequences may be supplemented with T2-weighted 3D fast spin-echo sequences, a technique that consistently yields images with high SNR and contrast-to-noise ratio, excellent contrast, and superior anatomic definition, as well as the ability to retrospectively generate multiplanar images (Fig 15). Images are acquired with 2-mm section thickness and should be obtained in the same plane as axial oblique T2-weighted FRFSE images. Occasionally, T2-weighted 3D fast spin echo MR imaging is limited by the inability to apply the "no phase wrap" function; in these cases, a larger FOV should be used to prevent aliasing. Moreover, this technique may limit the resolution of acquired images.

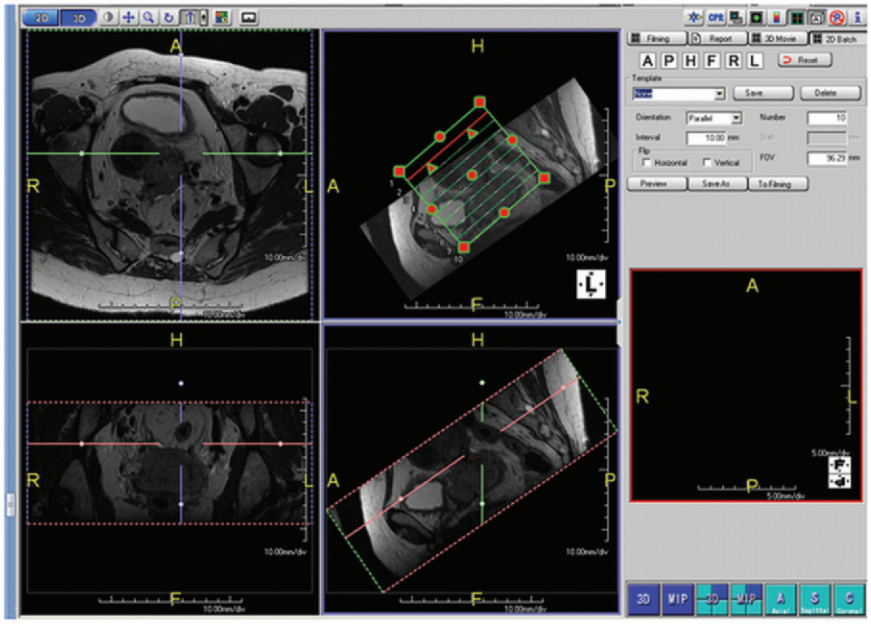
## Use of Vaginal Gel

In the literature, there is no consensus on the use of vaginal contrast material (2,9,20,28,48). Therefore, its use remains optional. Vaginal gel is useful for evaluating cervical cancer, especially

**Figure 15.** Use of T2-weighted 3D MR imaging to assess cervical cancer. **(a)** Axial oblique high-resolution T2-weighted FRFSE MR image shows a locally advanced cervical mass with bilateral parametrial extension (arrows) invading the posterior cul-de-sac and abutting the anterior rectal wall (arrowhead). **(b)** High-resolution T2-weighted 3D MR image with postprocessing and alteration of the angle of the oblique axial image shows a clear fat plane between the tumor and the anterior rectal wall (arrow), an important factor for planning radiation therapy. **(c)** Screen shot from a dedicated workstation shows the T2-weighted 3D MR images that were acquired, which may be reviewed in any imaging plane. The multiplanar reformation capability of high-resolution T2-weighted 3D MR imaging, in addition to its excellent contrast, is useful when additional anatomic detail is needed, such as in equivocal cases and for treatment planning.



a. b.



c.

in those who do not undergo evaluation with anesthesia. About 20–30 mL of warm ultrasonographic gel is placed in the vagina after positioning the patient on the table. Usually, vaginal contrast material is well tolerated and does not cause substantial discomfort. The use of gel contrast material yields areas of high signal intensity on T2-weighted images and provides excellent definition of vaginal fornices and the cervix, allowing for accurate assessment of vaginal involvement, especially in patients whose tumor has an exophytic cervical component (Fig 16).

## MR Imaging of Lymph Node Involvement

Metastasis to the regional lymph nodes is one of the most important prognostic factors in endometrial cancer and is included in the FIGO surgical staging of endometrial cancer. The involvement of nodes upstages endometrial cancer to

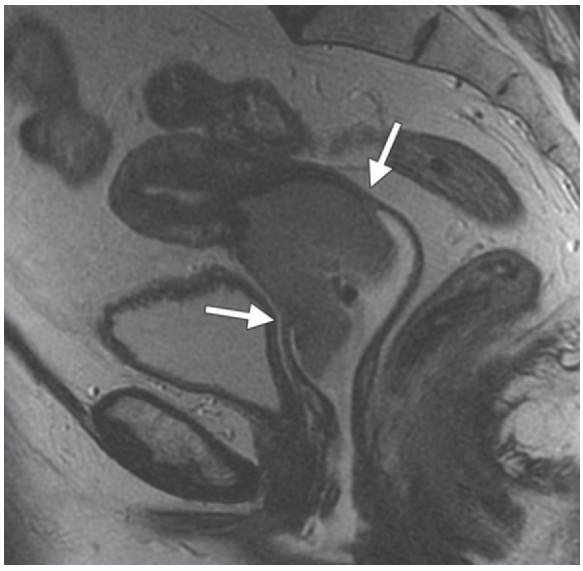


**Figure 16.** Use of endovaginal gel. Sagittal high-resolution T2-weighted FRFSE MR image shows a large mass replacing the anterior and posterior cervical lips and protruding into the upper one-third of the vagina. The high-signal-intensity endovaginal gel distends the vaginal fornices (arrows) and separates them from the intravaginal exophytic component of the tumor. The vaginal wall and forniceal insertions are separate from the tumor, and the normal low signal intensity of the muscular vaginal wall is preserved, excluding vaginal invasion.

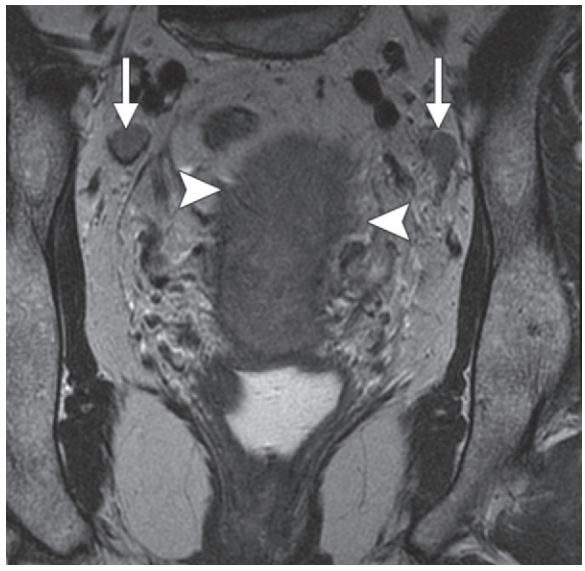


**Figure 17.** Metastatic lymphadenopathy. Coronal high-resolution T2-weighted FRFSE MR image shows a large cervical mass with bilateral parametrial extension (arrowheads) and bilateral external iliac lymphadenopathy (arrows). Lymph nodes have abnormal signal intensity, which matches that in the primary tumor. High-resolution MR imaging depicts abnormal alterations in nodal morphologic characteristics and signal intensity, even in normal-sized nodes, which increases its sensitivity for depicting disease.

stage IIIC1 or IIIC2, depending on whether the pelvic or paraaortic lymph nodes are involved (3). The FIGO staging of cervical cancer is clinical and does not include adenopathy. However, nodal involvement has significant prognostic implications and is important in treatment planning (20,28,49).

Assessment of nodal involvement with cross-sectional imaging techniques continues to rely on the size of lymph nodes, a method that has significant limitations, with sensitivity ranging from 38% to 89% and specificity ranging from 78% to 99% (20,49–53). Incorporating morphologic features of nodal involvement, which are best seen at high-resolution T2-weighted MR imaging and include internal heterogeneity, spiculated nodal margins, necrosis, and signal intensity comparable to that in the primary tumor, improves the accuracy of evaluation in patients with rectal cancer and may be applicable to those with endometrial or cervical cancer (54).

Teaching Point

High-resolution coronal T2-weighted imaging is best for assessing pelvic nodes (ie, the parametrial, obturator, internal and external iliac, and common iliac nodal stations) that may be involved in cervical and endometrial cancer (Fig 17). Obtaining axial T2-weighted fast spin echo series with a large FOV from the top of the kidneys through the L3 vertebra (FOV, 30–38 cm; section thickness, 5 mm) allows assessment of paraaortic lymphadenopathy and depicts hydronephrosis. More precise tailoring of the MR imaging protocol should be done on the basis of the type of gynecologic malignancy, with optional sequences used as needed to improve cancer staging (Table 3) (7,27).

## Conclusion

Optimization of MR imaging protocols with the use of thin-section high-resolution multiplanar T2-weighted images and simple modifications, such as the addition of double oblique T2-weighted, diffusion-weighted, and dynamic contrast-enhanced images, improves staging and treatment planning in patients with endometrial and cervical cancer.

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**Table 3: Pelvic Gynecologic High-Resolution MR Imaging Protocol**

| Type of Sequence | Pulse Sequence | Echo Time (msec) | Repetition Time (msec) | FOV (cm) | Section Thickness (mm) | Acquisition Time* | Comments |
|---|---|---|---|---|---|---|---|
| Main sequences | | | | | | | |
| Sagittal T2-weighted | FRFSE | 102 | >3000 | 20–24 | 3–4 | 4:08 | … |
| Coronal T2-weighted | FRFSE | 102 | >3000 | 18–22 | 3–4 | 6:00 | … |
| Axial T2-weighted | FSE | 102 | >3000 | 28–34 | 5 | 5:30 | Pelvic survey |
| Oblique axial T2-weighted | FRFSE | 102 | 4500 | 18 | 3–4 | 6:25 | … |
| Axial T2-weighted upper body | FSE | 102 | 3000–5000 | 28–34 | 5 | 4:25 | Retroperitoneal survey |
| Axial oblique diffusion-weighted | Diffusion-weighted EPI | 75 | 1200 | 30–38 | 4–5 | 2:30 | Match plane to that used in axial oblique T2-weighted imaging |
| Optional sequences | | | | | | | |
| Double oblique axial T2-weighted | FRFSE | 102 | 4500 | 18 | 3–4 | 6:25 | Used if uterus or cervix is off midline |
| Sagittal FS 3D DCE | FSPGR | 2 | 5.1 | 22 | 3–4 | 3:21 | Cover uterus at 25, 60, and 120 sec or continuously image for 2 min; used for endometrial cancer |
| Axial oblique contrast-enhanced 3D | FSPGR | 2 | 5.1 | 22–28 | 3–4 | 2:00 | 3–4-min delay; used for endometrial cancer |
| Axial T2-weighted 3D | 3D FSE | Variable | 2000 | 22–28 | 2 | 7:00 | … |

Note.—DCE = dynamic contrast-enhanced, EPI = echo-planar imaging, FRFSE = fast recovery fast spin echo, FSE = fast spin echo, FS = fat saturation, FSPGR = fast spoiled gradient echo, 3D = three-dimensional.
*Length of time in minutes and seconds.


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# Optimization of MR Imaging for Pretreatment Evaluation of Patients with Endometrial and Cervical Cancer

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**Page 1084**
T2-weighted MR imaging is the key sequence for evaluating myometrial invasion because it depicts the uterine zonal anatomy, with the intermediate-signal-intensity tumor well delineated against the low-signal-intensity junctional zone (Fig 1) (7–9,11).

**Page 1085**
High-resolution double oblique images provide a true orthogonal view of the uterus, with the potential to avoid volume averaging, and they improve assessment of myometrial invasion (Fig 3).

**Page 1086**
The advantage of multiplanar high-resolution MR imaging for tumor staging is its improved spatial resolution and depiction of disease extent in more than one plane, which are essential for accurate staging (Fig 6) (4,33).

**Page 1093**
The T2-weighted sequences may be supplemented with T2-weighted 3D fast spin-echo sequences, a technique that consistently yields images with high SNR and contrast-to-noise ratio, excellent contrast, and superior anatomic definition, as well as the ability to retrospectively generate multiplanar images (Fig 15).

**Page 1095**
Incorporating morphologic features of nodal involvement, which are best seen at high-resolution T2-weighted MR imaging and include internal heterogeneity, spiculated nodal margins, necrosis, and signal intensity comparable to that in the primary tumor, improves the accuracy of evaluation in patients with rectal cancer and may be applicable to those with endometrial or cervical cancer (54).