MAJOR PAPER

Visualization of Ovarian Tumors using 3T MR Imaging: Diagnostic Effectiveness and Difficulties

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(Received August 12, 2011; Accepted April 4, 2012)

Purpose: We evaluated the diagnostic effectiveness of magnetic resonance (MR) imaging at 3 tesla to visualize ovarian tumors and problems associated with its use.

Materials and Methods: From the records of 423 consecutive women who underwent pelvic MR imaging using a 3T system from April 2009 to June 2010, we analyzed 50 continuous cases of ovarian tumors proved by histopathology. We evaluated visualization of these tumors for image quality and artifacts using 5-point scales. For qualitative assessment, we scored overall image quality (1, poor, to 5, excellent), degree of conviction regarding the diagnosis (1, undiagnosable, to 5, diagnosable with high certainty), and 4 representative artifacts (penetrating, chemical shift, motion, and susceptibility artifact) (1, severe, to 5, little degradation). We also retrospectively reviewed the diagnostic features of the ovarian tumors and preoperative diagnostic accuracy. For quantitative assessment, we determined tumor size and ADC value.

Results: Overall quality score was scored 4.9±0.5, and conviction regarding diagnosis was 4.9±0.3. Artifacts caused little degradation in most cases: penetrating, 4.8±0.5; chemical shift, 4.3±0.5; motion, 4.6±0.6; and susceptibility, 3.8±0.9. Preoperative diagnostic accuracy was 92% (sensitivity 94.7%, specificity 90.3%). Mean tumor diameter was 88.3±61 mm. The mean ADC value was 1.04±0.3 in malignant tumors and 1.15±0.5 (×10⁻⁶ mm²/s) in benign tumors.

Conclusion: The quality of ovarian tumor images obtained with a 3T MR imaging system is adequate for diagnosis, with only slight degradation from penetrating or susceptibility artifacts.

Keywords: MRI, ovary, 3T

Introduction

Recently, magnetic resonance (MR) imaging with field strength of 3 tesla or higher has become available for clinical and research use. Theoretically, the signal-to-noise ratio (SNR) obtained by 3T MR imaging should be double that obtained at 1.5T, and the gain in SNR could be used to reduce scanning time or reduce the voxel size for high resolution images to less than one mm.¹² Numerous reports have documented the advantages of the 3T MR imaging system over the 1.5T system for morphological evaluation, functional imaging, and spectroscopy of the brain.¹³–⁷ However, in practice, the SNR increases but does not double, probably as a result of signal inhomogeneity or some artifacts,¹² and improved image quality at 3T is countered by drawbacks that include greater susceptibility effect, increased specific absorption rate (SAR), and radiofrequency (RF) field inhomogeneity. All these problems are more pronounced for MR imaging of the trunk.⁸

We believe the diagnostic effectiveness of MR imaging at 3T for ovarian tumors has not been detailed; therefore, we evaluated the quality of images obtained at 3T and the appearance of artifacts expected to be more severe at higher magnetic
fields.

**Materials and Methods**

**Study population (Table 1)**

A retrospective review of our institute’s MR imaging database records from April 2009 to June 2010 yielded 423 consecutive women who underwent pelvic MR imaging using a 3T system. Of these, we enrolled 50 (aged 21 to 74 years, mean 51 years) who had ovarian tumors with histopathological proof. Their tumors included 19 malignant tumors (15 ovarian carcinomas, 3 borderline malignant tumors, one metastatic tumor) and 31 benign tumors (10 dermoid cysts, 10 chocolate cysts, 7 cystadenomas, 2 fibromas, one adenofibroma and one cystadenoma with benign Brenner tumor).

**MR imaging scanning protocol**

MR images were obtained using a 3T MR imaging unit (Magnetom Verio; Siemens, Erlangen, Germany). Forty-eight of the 50 underwent gadolinium enhancement; 2 patients with chronic renal failure did not receive gadolinium. During imaging, the 48 with enhanced study received continuous intravenous infusion of 20 mg of hyoscine butylbromide (Buscopan; Boehringer Ingelheim Ltd., Bracknell, Berkshire, UK) diluted with 50 mL saline, unless contraindicated, to reduce peristalsis-induced image blurring. The imaging protocols applied were: for axial and sagittal T2-weighted turbo spin-echo images (T2WI)–repetition time (TR)/echo time (TE), 4000 ms/89 ms; echo-train length, 19; slice thickness, 3 mm; matrix, 512/307; and field of vision (FOV), 200 × 200 mm; for axial turbo spin-echo T1-weighted images (T1WI)–TR/TE, 450 ms/12 ms; slice thickness, 3 mm; and matrix, 320/192; for dynamic gadolinium-enhanced (precontrast, arterial phase, venous phase, delayed phase), 3-dimensional (3D) gradient-echo with fat suppression–TR/TE, 3.74 ms/1.38 ms; slice thickness, one mm; matrix, 256/167; FOV, 250 × 200 mm; and for diffusion-weighted images (DWI) obtained in the axial plane using single-shot spin-echo planar with chemical shift selective fat-suppression technique–TR/TE, 9900 ms/70 ms; slice thickness, 4.5 mm; matrix, 128/94; and FOV, 300 × 300 mm. The b-value were 0 and 800 s/mm².

**Image Evaluation**

**Qualitative assessment**

Two readers with 2 and 10 years’ experience interpreting gynecological MR images assessed the images with no prior knowledge of histological diagnosis. After reaching agreement regarding the 5-point assessment scale before the reading session, the 2 reviewers evaluated the MR images of the 50 ovarian tumors and reached decisions by consensus.

**Image quality**

Using 5-point scales, they graded overall image quality (1, poor, to 5, excellent) and degree of conviction regarding diagnosis (1, undiagnosable, to 5, diagnosable with high certainty).

**Artifacts**

We used a 5-point scale to assess image degradation (1, severe degradation, to 5, little degradation) caused by penetration, chemical shift, motion, and susceptibility artifacts, 4 factors that can cause severe image degradation at higher magnetic fields. A score of 5 signified excellent image quality, with almost no artifacts; a score of 3 indicated image quality degraded by artifacts sufficient to interfere with accurate diagnosis.

**Diagnostic value**

We also retrospectively reviewed the diagnostic features of ovarian tumors and preoperative diagnostic accuracy.

As features for diagnosis, we used previously established findings to distinguish malignant ovarian tumor. Primary findings for malignancy are (a) tumor size exceeding 4 cm, (b) bilateral tumors, (c) predominantly solid tumor, (d) necrosis in a solid lesion, and (e) cystic lesion with wall or septal thickness greater than 3 mm or papillary projections. Secondary associated findings include (a) involvement of the pelvic organs or side wall, (b) peritoneal metastasis, (c) ascites, and (d) adenopathy.9,10 We also evaluated 2 benign findings—a regular and homogeneous solid component with low signal intensity on T2WI or a fat component on T1WI with fat suppression.11,12
with homogeneous low signal intensity on T2WI is a
typical finding of benign fibrothecoma. Fat-contain-
ting tumors are usually benign mature cystic ter-
atomas, but rarely represent immature teratoma or
malignant transformation.

One reader (J.T.) reviewed the presurgical im-
ages of the 50 ovarian tumors for these established
findings. We then retrospectively reviewed diagnostic
sensitivity, specificity, and accuracy from the
reports of the MR examination.

**Quantitative Assessment**

One reader (T.U.) analyzed tumor diameter. The
axial and sagittal T2-weighted images were used to
determine the size and location of the tumors. The
long-axis diameter was measured using electronic
calipers on the workstation.

The same reader measured apparent diffusion
coefficient (ADC) value on a satellite console of the
MR imaging unit. The mean ADC values (×10⁻⁶
mm²/s) were measured in 18 of 19 malignant
tumors with a solid part, in 3 benign tumors (2
fibromas, one adenofibroma), and in 7 dermoid
cysts. One mucinous cystadenocarcinoma and 3
dermoid cysts had solid parts too small to measure
and were excluded from analysis of ADC value.
Using ADC maps on the workstation, we measured
the mean ADC value in a circular region of interest
(ROI) in one representative region as large as possi-
ble within the ovarian tumor. The ROI was placed
on the solid portion of the tumor with care to avoid
the cystic area and the area affected by the artifact.

**Statistical analysis**

We used an unpaired t-test to compare the ADC
values among 18 malignant tumors and 3 benign
solid tumors (2 fibromas, one adenofibroma). P<
0.05 was considered statistically significant. Statis-
tical analyses were performed using Graphpad
Prism Software (Graphpad Prism for Mac, version
5.0c, Graphpad Software, CA, USA).

**Results**

**Qualitative assessment (Tables 2 and 3)**

The score of overall quality was 4.9±0.5 (range,
3 to 5), and the score of accuracy of diagnosis was
4.9±0.3 (range, 4 to 5). The overall quality was
graded 4 or 5 in almost all, and no cases were grad-
ed 1 or 2. Conviction regarding diagnosis was also
graded 4 or 5 in all cases (Table 2).

Artifacts were scored as follows: penetration,
4.8±0.5 (range, 3 to 5); chemical shift, 4.3±0.5
(range, 4 to 5); motion, 4.6±0.6 (range, 3 to 5);
and susceptibility, 3.8±0.9 (range, 3 to 5) (Table
3). Three cases scored 3 or less for penetration ar-
tifact, one case for motion artifact, and 23 for sus-
ceptibility artifacts. Figures 1 to 5 show representa-
tive images.

**Diagnostic value**

The diagnostic features of ovarian tumors were
observed clearly (Table 4), and based on these es-
established features, 28 of 31 benign tumors and 18
of 19 malignant tumors were correctly diagnosed
before operation. One patient with mucinous cysta-
denocarcinoma was misdiagnosed with benign
mucinous cystadenoma. One fibroma, one fibro-
adenoma, and one cystadenoma with benign Bren-
ger tumor were misdiagnosed as malignant ovarian
lesions. MR imaging at 3T demonstrated 94.7%
sensitivity, 90.3% specificity, and 92% accuracy

**Table 2. Image Quality**

<table>
<thead>
<tr>
<th>Score</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Overall image quality</td>
<td>0</td>
</tr>
<tr>
<td>Accuracy of diagnosis</td>
<td>0</td>
</tr>
</tbody>
</table>

Overall image quality: 1, poor, to 5, excellent; accuracy of diagnosis: 1, undiagnosable, to 5, diagnosable with high certainty. SD, standard deviation.

**Table 3. Artifacts**

<table>
<thead>
<tr>
<th>Score</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1: Severe</td>
</tr>
<tr>
<td>Penetration artifact</td>
<td>0</td>
</tr>
<tr>
<td>Chemical shift artifact</td>
<td>0</td>
</tr>
<tr>
<td>Motion artifact</td>
<td>0</td>
</tr>
<tr>
<td>Susceptibility artifact</td>
<td>0</td>
</tr>
</tbody>
</table>

SD, standard deviation.

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Fig. 1. Serous papillary adenocarcinoma in a 62-year-old woman. This case had excellent quality; overall image quality was scored as 5. (a) Sagittal T2-weighted magnetic resonance (MR) image clearly shows a large solid and cystic tumor (arrows). (b) Axial gadolinium-enhanced T1-weighted MR image shows a cystic and abundantly solid mass (arrows). (c) Axial diffusion-weighted imaging (DWI) shows a hyperintense solid component (arrows).

Fig. 2. A 59-year-old female patient with a massive mucinous cystic borderline tumor. T2-weighted axial image obtained by 3T magnetic resonance (MR) imaging shows significant signal loss in the central part of the tumor. The peripheral part is not affected by the penetration artifact. This case was graded as 3 for penetration artifact.

Fig. 3. Bilateral dermoid cysts in a 42-year-old woman. T2-weighted axial image shows chemical shift artifacts at the boundary between the floating debris and fatty component in dermoid cysts. This case was graded as 4 for chemical shift artifact.

Quantitative assessment
Mean tumor diameter was $88.3 \pm 61$ mm (range, 13 to 342 mm). Mean ADC values were $1.04 \pm 0.3 \times 10^{-6}$ mm$^2$/s for the 18 malignant tumors, 1.15
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±0.5 (×10⁻⁶ mm²/s) for the 3 benign tumors, and 1.47±0.3 (×10⁻⁶ mm²/s) for the 7 dermoid cysts. Although the sample size was too small to determine significant difference, the malignant tumors tended to have lower ADC values than benign tumors (P=0.5647) (Fig. 6).

Discussion

MR imaging using anatomic, chemical, and functional information has huge potential for the management of the gynecologic patient. Though transabdominal or transvaginal ultrasound is the first choice for evaluating suspected adnexal masses, MR imaging is a cost-effective next step when ultrasonographic findings are indeterminate.²⁻⁴ MR imaging is now recommended as well as a problem-solving modality for assessing complex adnexal masses.¹⁰⁻¹²

Several reports have considered the value of MR imaging at 3T for examining the female pelvis. Morakkabati-Spitz and associates observed equiva-

Table 4. MR findings of ovarian tumors: differentiation between malignant and benign tumors

<table>
<thead>
<tr>
<th>Malignant Findings</th>
<th>Malignant tumors</th>
<th>Benign tumors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) tumor size &gt; 4 cm</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>(b) presence bilaterally</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>(c) predominantly solid</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>(d) necrosis lesion</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>(e) wall or septal thickness &gt; 3 mm or papillary projections</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Secondary Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) involvement of pelvic organs or side wall</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(b) peritoneal metastasis</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>(c) ascites</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>(d) adenopathy</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Benign Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>low intensity on T₂WI</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>fat components</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 4. Right dermoid cyst in a 66-year-old woman. T₂-weighted axial image shows image blur because the patient was unable to keep her body still during the examination. This case was graded as 3 for motion artifact.

Fig. 5. Right chocolate cyst in a 35-year-old woman. This case was graded as 3 for susceptibility artifact. (a) T₂-weighted axial image shows chocolate cyst of high intensity in Douglas pouch close to rectal gas. (b) Axial diffusion-weighted imaging (DWI) shows susceptibility artifact from gas within the bowel (arrow).
lent image quality between 1.5- and 3T MR images of the pelvis and found that choosing comparable parameters at 3T to those for 1.5T MR imaging maintained the familiar tissue contrast of the pelvic anatomy. Recently, the clinical use of MR imaging at 3T has increased for female pelvic lesions. Hori and colleagues reported that 3 and 1.5T MR imaging are comparable for presurgical evaluation of patients with cervical cancer, and Torricelli’s team reported comparably high diagnostic accuracy of MR imaging at 3 and 1.5T in evaluating the depth of myometrial infiltration of endometrial cancer.

Although image quality is improved at 3T, use of this magnetic field has several drawbacks, including RF field inhomogeneity, chemical shift artifacts, motion artifacts, and greater susceptibility effect. Inhomogeneity of the RF field, or $B_1$, is related to the shorter RF wavelength at 3T; at 3T, in water, the RF wavelength becomes 26 cm, half that at 1.5T, and approximates the dimensions of the body. Because the RF penetration effect is inversely proportional to the RF wavelength, at 3T, the RF dose does not reach deep into the body, and so, signal drops off at the center of the body. Shorter waves also tend to cause more severe RF wave interference in the body in addition to RF field inhomogeneity and a locally irregular flip angle, and they can lead to bright or dark areas, termed standing wave effect. These artifacts are more prominent for a larger target relative to the RF wavelength. These pose problems in patients with bulky cystic tumors or massive ascites; malignant ovarian tumors often present these imaging manifestations. In our study, the mean tumor diameter was 88.3 mm (range, 13 to 342 mm). Images of 47 of the 50 cases were graded 4 (slight/weak) or 5 (very little/negligible) for penetration artifact, suggesting that this artifact is no longer a major problem due to improvements in the MR imaging, coils, sequences, and image processing. Only 3 of our 50 cases were scored 3, and they showed bulky cystic tumors (one mucinous cystadenocarcinoma with 273-mm diameter, and 2 mucinous adenomas with diameters of 269 and 342 mm) (Fig. 2). Though moderate penetrating artifact in these 3 cases produced a drop in signal in the cystic contents, it did not markedly affect evaluation of the cystic wall of the tumors. The key diagnostic feature is usually the mural nodule, so penetrating artifact can be tolerated for clinical diagnosis of large ovarian tumors, even cystic lesions with diameters exceeding 250 mm.

Chemical shift artifact in the frequency-encoding direction shifts the signal from lipid relative to water by a fixed number of pixels. At 3T, water resonates at a frequency 420 to 440 Hz higher than lipids. Thus, the fat-water chemical shift amounts to twice the number of pixels compared as with 1.5T imaging, which leads to noticeable bright/dark rims around tissue interfaces. These can be eliminated using fat suppression techniques, but some information about the soft tissue within the pelvis may then be lost. We observed chemical shift artifacts at the boundary between the floating debris and fatty component in dermoid cysts and between the ascites and intra-abdominal fat. No cases were graded as 3 or less for chemical shift artifacts because visualization of ovarian tumors was not impaired.

The motion artifacts associated with respiration and bowel peristalsis also tend to be more prominent in MR imaging at 3T. Such artifacts can usually be reduced by positioning a rest slab on the anterior abdominal wall or using antiperistaltic agents. Von Falkenhausen and colleagues reported a significant difference in the number and severity of these artifacts during liver evaluation at 1.5 and 3T. In one of our study patients who was unable to keep her body still during examination, motion artifact was graded as 3; moderate. Most other cases were graded 4 or 5. This suggests that motion artifacts may not generally affect image quality in MR imaging at 3T. The artifacts were more common and severe in the upper abdomen than the pelvis.

Local variations in the main magnetic field cause susceptibility artifact, which includes image distor-
visualization and local areas of hypo- or hyperintensity, especially in DWI and gradient-echo sequences. Although it was originally believed that abdominal imaging would be compromised by susceptibility artifact due to gas within the bowel, doubling the receiver bandwidth can reduce this artifact to levels seen at 1.5T. Ingested items that produce susceptibility artifact, including iron tablets and steel shot, are occasionally seen and may necessitate rescanning after an appropriate time interval. Previous studies of MR imaging at 3T have revealed no substantial susceptibility artifact that reduces diagnostic performance in the preoperative evaluation of patients with endometrial carcinoma and cervical carcinoma. Because ovarian tumors often tend to be massive intra pelvic-abdominal pathologies closer to not only the rectum but also the small intestine, we expected more substantial susceptibility artifact than that seen in uterine lesions. In our study, 23 of the 50 cases were graded as 3, i.e., moderate for susceptibility artifact. The diagnostic accuracy of DWI for differentiating malignant ovarian lesions from benign lesions has already been established, which may limit the utility of DWI at 3T MR imaging. We also analyzed the ADC values of these lesions. Although susceptibility artifact produced a little degradation, it was still possible to measure the solid part of the ovarian lesions. Furthermore, although the number of benign tumors with a solid part in our study was too small to determine any significant difference in ADC value between benign and malignant lesions, malignant tumors tended to have lower ADC values (Fig. 6).

The MR features of ovarian malignant tumors have already been established and widely applied for clinical diagnosis. The typical important features of malignant tumors and some benign tumors were clearly obtained in our 50 cases. Regarding these classical diagnostic features, preoperative diagnosis obtained satisfactory results–94.7% sensitivity, 90.3% specificity, and 92% accuracy. Meta-analysis in the past suggested that the sensitivity and specificity of ultrasonography (US), computed tomography (CT), and MR imaging for ovarian tumor characterization are comparable: 89% sensitivity (95% confidence interval [CI], 88 to 90%) and 84% specificity (95% CI, 82 to 86%) for US; 85% sensitivity (95% CI, 83 to 86%) and 86% specificity (95% CI, 76 to 92%) for CT; and 89% sensitivity (95% CI, 88 to 92%) and 86% specificity (95% CI, 84 to 88%) for MR imaging. In our study, MR imaging at 3T demonstrated results comparable to those of conventional 1.5T MR imaging, US, and CT for the diagnosis of ovarian tumors.

Our study has some limitations. We made no intraindividual comparison. Neither did we account for body mass index; the groups of Sreenivas and Merkle reported more prominent inhomogeneity of signal intensity in obese patients. Our sample size was too small to determine significant difference in ADC values between benign and malignant ovarian tumors, and the small sample precluded comparison of diagnostic accuracy. It is premature to conclude that 3T MR imaging has any advantage over 1.5T imaging in the diagnosis of ovarian tumors and further studies are needed to confirm the results.

In summary, our results demonstrate that MR imaging at 1.5 and 3T are equally useful for evaluating ovarian tumors. Imaging at 3T offers high diagnostic accuracy, with image quality sufficient to allow diagnosis of ovarian tumors and minimal degradation from penetration and susceptibility artifacts.

Acknowledgement

We thank Masato Uchikoshi (Siemens Japan K. K.) for excellent technical assistance and advice regarding sequence optimization.

References