Cystic Ovarian Lesions in SSFP Diffusion Imaging

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(Received March 29, 2002; Accepted December 12, 2002)

Purpose: MR assessments of ovarian cystic lesions are usually based on morphological features, signal intensities and enhancement with contrast media. This study was performed to evaluate the usefulness of the steady-state free precession (SSFP) diffusion imaging of cystic ovarian lesions for analyzing cystic contents.

Materials and Methods: Sixty-one ovarian cystic lesions in 37 patients were examined. The diffusion-related coefficient (DRC) and the ratio of the relative apparent diffusion coefficient of the lesion to that of subcutaneous fat tissue (rADCL/rADC₅) were calculated from SSFP diffusion images.

Results: The DRCs and the rADCL/rADC₅ ratios in endometrial cysts and in the fatty parts of dermoid cysts were significantly lower than in other cystic tumors.

Conclusion: SSFP diffusion imaging can be included in clinical practice to analyze ovarian cystic lesions within a short scan time; the DRC and the rADCL/rADC₅ ratio are useful for evaluating cystic contents.

Keywords: MRI, diffusion study, ovary, neoplasm

Introduction

In the assessment of ovarian cystic tumors, magnetic resonance (MR) imaging plays an important role in distinguishing between benign and malignant tumors. It does so mainly through morphological features, signal intensities and enhancement with contrast media. However, the signal intensity of the cystic contents is not specific enough to aid in differential diagnosis of ovarian cystic tumors except in the distinguishing of hemorrhagic fluid of endometrial cysts, fat of dermoid cysts and the colloid contents of struma ovarii.²⁻⁴

Diffusion-weighted MR imaging, an echo-planar imaging (EPI) technique, reflects the mobility of water molecules and is mainly applied to brain diffusion imaging. Diffusion-weighted MR imaging seems an attractive sequence for assessing cystic contents because it can differentiate between arachnoid cysts and epidermoid cysts.² Diffusion-weighted EPI in the pelvic region shows image distortion caused by susceptibility artifacts due to air as well as strong chemical shift artifacts from fatty tissue. In addition, the signal-to-noise ratio and spatial resolution with diffusion-weighted EPI are relatively low.

In contrast, the steady-state free precession (SSFP) sequence can be used for diffusion-weighted imaging, resulting in relatively few susceptibility artifacts due to air or fat. It has thus been applied in brain and bone marrow diffusion imaging. In SSFP diffusion imaging, the signals are affected by all previous diffusion-sensitizing gradients; therefore strong diffusion-weighted images can be obtained with less image distortion.²

The purpose of the present study was to evaluate the usefulness of SSFP diffusion imaging in assess-
ing cystic ovarian lesions.

Materials and Methods

Sixty-one ovarian cystic lesions in 37 patients (15–60 years old, with a mean age of 36.3) were assessed in this study. Thirty-nine of the 61 lesions were surgically removed and pathological confirmation was obtained as follows: 8 serous cystic tumors (1 cystadenoma, 6 borderline malignancy, 1 cystadenocarcinoma); 15 mucinous cystic tumors (13 cystadenoma, 2 cystadenocarcinoma); and 16 dermoid cysts. The remaining twenty-two lesions were not surgically removed as they were diagnosed as benign endometrial cysts based on clinical manifestations and MR imaging features.²

In the present study, we classified ovarian cystic lesions into five groups: serous cystic tumors (n = 8), mucinous cystic tumors (n = 15), and endometrial cysts (n = 22). We evaluated the cystic parts and the fatty parts of dermoid cysts separately. The cystic parts of the dermoid cysts had the same signal intensities as urine in both T₁-, and T₂-weighted images (n = 16). The fatty parts of dermoid cysts had high signal intensities on T₁-weighted images and suppressed signal intensities on T₂-weighted images of fat saturation (FS), as with subcutaneous fat tissue (n = 8).

MR imaging was performed with a 1.5T superconductive scanner (Vision; Siemens, Erlangen, Germany). T₁-weighted spin-echo (TR = 500 ms / TE = 12 ms) images with or without FS and T₂-weighted turbo spin-echo (TR = 3500 ms / TE eff = 100 ms / echo train length = 11) images with FS were obtained in the sagittal and axial planes. The field of view was 250 mm, the slice thickness was 5 or 7 mm (gap 20%), and the number of acquisitions was two. Data were collected with a 256 × 256 matrix and a pelvic phased-array coil.

From the T₂-weighted images, we selected the appropriate slice in which the cystic lesion was visualized at its largest size and performed SSFP diffusion imaging (time-reversed fast imaging with steady-state precession [PSIF] with diffusion-sensitizing gradient) under breath-holding (TR = 30 ms, flip angle = 50°, diffusion pulse length δ = 1, 4, 8, 12 ms, 1 acquisition) for a scan time of 12–15 seconds.

It is known that with flip angles of less than 90°, the MR signal is composed of the sum of primary echoes, stimulated echoes and higher-order echoes.¹⁰ Therefore, the application of a diffusion-sensitizing gradient within a PSIF sequence makes the technique attractive because the diffusion time Δ can now be in the range of T₁ time.¹¹,¹² Because signal generation in the diffusion-weighted SSFP sequence is complex, it is not possible to characterize the strength of the sequence with a simple b-value in diffusion-weighted spin-echo sequences.⁷ Therefore, we compared the effect of the diffusion strength with the two methods explained below.

Comparison of DRC

A circular region of interest (ROI) with a diameter exceeding 15 mm was placed in the cystic contents on the diffusion image and the signal intensity of the lesion was measured on each δ value. Because the signal decreases exponentially as the diffusion strength increases, we graphed the relationship between the signal intensity and the δ value and used exponential curve fitting. The exponential coefficients, defined as the diffusion-related coefficient (DRC), were compared among the five groups. Values were expressed as means, ± standard deviations.

Comparison of the rADCₙ / rADCₓ ratio

To eliminate the differences in the scaling factor, we examined whether subcutaneous fat could be used as the internal standard reference. With the water phantom placed adjacent to the body, the relative apparent diffusion coefficient of water (rADCₓ) and that of subcutaneous fat tissue (rADCₙ) were calculated using two diffusion images (δ = 1 and 12 ms) in the initial 10 patients:

\[
rADCₓ = \ln (Sₓ₁ / Sₓ₁₂),
\]

\[
rADCₙ = \ln (Sₙ₁ / Sₙ₁₂),
\]

where Sₓ₁ was the signal intensity of the water phantom in the diffusion image (δ = 1 ms), Sₓ₁₂ was the signal intensity of the water phantom in the diffusion image (δ = 12 ms), Sₙ₁ was the signal intensity of subcutaneous fat tissue in the diffusion image (δ = 1 ms) and Sₙ₁₂ was the signal intensity of subcutaneous fat tissue in the diffusion image (δ = 12 ms). We then assessed whether the rADCₓ / rADCₙ ratios in these different patients were constant.

Next, the relative apparent diffusion coefficient of the lesion (rADCₙ) was also calculated with two diffusion images (δ = 1 and 12 ms) in all patients.

\[
rADCₙ = \ln (Sₙ₁ / Sₙ₁₂),
\]

where Sₙ₁ was the signal intensity of the lesion in the diffusion image (δ = 1 ms) and Sₙ₁₂ was the signal intensity of the lesion in the diffusion image (δ = 12 ms).

We compared the rADCₙ / rADCₓ ratios among the various ovarian cystic lesions for quantitative analysis. Values were expressed as means, ± standard deviations.

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Statistical analysis
In each study, to determine the statistical significance of the difference among the five groups, we used one-way analysis of variance (ANOVA) and the Tukey test for multiple comparisons. A P value of less than 0.05 was considered statistically significant.

Results
Comparison of DRC
The DRC of each group was as follows: serous cystic tumor, 0.230 ± 0.059; mucinous cystic tumor, 0.217 ± 0.051; endometrial cyst, 0.143 ± 0.045; cystic part of dermoid cyst, 0.252 ± 0.052; and fatty part of dermoid cyst, 0.127 ± 0.059 (Fig. 1, Table 1). The mean DRCs were statistically significant between endometrial cyst and serous cystic tumor; endometrial cyst and cystic part of dermoid cyst; serous cystic tumor and fatty part of dermoid cyst; mucinous cystic tumor and fatty part of dermoid cyst; cystic part of dermoid cyst and fatty part of dermoid cyst (p < 0.01); and endometrial cyst and mucinous cystic tumor (p < 0.05). However, the mean DRCs did not differ significantly between serous cystic tumor and mucinous cystic tumor.

Comparison of the rADC_L/rADC_F ratio
In 10 patients, the rADC_L, rADC_F, and rADC_L/rADC_F ratios were 3430 ± 102, 2136 ± 98 and 1.606 ± 0.038, respectively. The rADC_L/rADC_F ratios were almost constant among the different patients: the 95% confidence interval of the mean rADC_L/rADC_F ratio ranged from 1.577 to 1.645. Therefore, we used subcutaneous fat as the internal standard reference.

Figure 2 shows the distribution of the rADC_L/rADC_F ratios in five groups. The rADC_L/rADC_F ratio of each group is shown in Table 2. The mean rADC_L/rADC_F ratios were statistically significant between endometrial cyst and serous cystic tumor; endometrial cyst and mucinous cystic tumor; endometrial cyst and cystic part of dermoid cyst; serous cystic tumor and fatty part of dermoid cyst; mucinous cystic tumor and fatty part of dermoid cyst; and mucinous cystic tumor and cystic part of dermoid cyst (p < 0.01) (Figs. 3, 4). The differences between the mean rADC_L/rADC_F ratios for serous cystic tumor and mucinous cystic tumor were not significant.

Discussion
Prior to surgery for a cystic ovarian tumor, even...
Fig. 2. Distribution of the $rADCL/WrADCF$ ratios of ovarian cystic lesions
The $rADCL/WrADCF$ ratios of endometrial cysts (EM) and the fatty part of dermoid cysts (DF) were significantly lower than those of serous cystic tumors (SCY), mucinous cystic tumors (MCY) and the cystic part of dermoid cysts (DCY). Although the $rADCL/WrADCF$ ratios between MCY and SCY were not significantly different, the differences in the $rADCL/WrADCF$ ratios between MCY and DCY were significant.

Table 2. Comparison of $rADCL/WrADCF$ ratio among ovarian cystic lesions

<table>
<thead>
<tr>
<th>No. of Lesions</th>
<th>$rADCL/WrADCF$ Ratio</th>
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<tbody>
<tr>
<td>Serous cystic tumor</td>
<td>8 1.344 ±0.127</td>
</tr>
<tr>
<td>Mucinous cystic tumor</td>
<td>15 1.341 ±0.117</td>
</tr>
<tr>
<td>Endometrial cyst</td>
<td>22 1.156 ±0.060</td>
</tr>
<tr>
<td>Cystic part of dermoid cyst</td>
<td>16 1.585 ±0.112</td>
</tr>
<tr>
<td>Fatty part of dermoid cyst</td>
<td>8 1.089 ±0.087</td>
</tr>
</tbody>
</table>

Note: Data are given as the mean ± standard deviation.
$rADCL = $ relative apparent diffusion coefficient of lesion
$wADCF = $ relative apparent diffusion coefficient of subcutaneous fat tissue

Possibly increasing the risk of pseudomyxoma peritonei. In the present study, we assessed whether diffusion information could predict the features of cystic contents in ovarian lesions.

Although there exists a previous report on diffusion-weighted EPI of ovarian tumors, questions have been raised concerning the accuracy of the evaluation of a small loculus and a loculus near air-filled bowel due to low spatial resolution and high image distortion.

SSFP diffusion imaging causes fewer susceptibility artifacts than does diffusion-weighted EPI. In SSFP diffusion imaging, the signals are affected by all previous diffusion-sensitizing gradients; therefore, strong diffusion-weighted images can be obtained with less image distortion.

We found the DRCs and the $rADCL/WrADCF$ ratios of endometrial cysts and of the fatty portions of dermoid cysts were significantly lower than those of other cystic tumors. However, the DRCs and the $rADCL/WrADCF$ ratios between mucinous cystic tumors and serous cystic tumors were not significantly different. These results correspond to results in previous reports. In 4 of 8 serous tumors in our report, hemorrhage was identified on T1-weighted images and confirmed in surgery. Katayama previously reported that the signal intensities of lesions on both T1- and T2-weighted images affected the ADCs. Therefore, we suspected hemorrhage as one variable affecting the DRC and the $rADCL/WrADCF$ ratio. Excluding six hemorrhage-containing tumors (4 serous tumors and 2 mucinous tumors), the DRC and the $rADCL/WrADCF$ ratio of serous tumors were 0.258 ±0.025 and 1.428 ±0.036. These values were higher than those of mucinous tumors (the DRC was 0.225 ±0.049; the $rADCL/WrADCF$ ratio was 1.376 ±0.065) and each standard deviation was lower. However, these differences were not statistically significant. When the threshold value of the DRC for differentiation between serous cystic tumors and mucinous cystic tumors was defined as 0.22, the accuracy was 0.80. When the threshold ratio of $rADCL/WrADCF$ was defined as 1.400, the accuracy was 0.76. Assessing T2-weighted images, we focused on the multiplicity of cyst loculi; a multilocular cystic tumor without fat component or demonstrable hemorrhage was defined as a mucinous tumor. The accuracy of T2-weighted imaging for differentiation between serous cystic tumors and mucinous cystic tumors was 0.70, not significantly different from those of DRC-based diagnosis and of $rADCL/WrADCF$ ratio-based diagnosis.

Most serous tumors (7 of 8) in the present study had a malignant potential, which might also have affected the DRC and the $rADCL/WrADCF$ ratio. On the other hand, significant differences were found between the $rADCL/WrADCF$ ratios of mucinous cystic tumors and the cystic part of dermoid cysts with no hemorrhage or malignant portions. This finding suggests it might be possible to differentiate mucinous tumors from serous tumors with SSFP diffusion imaging, although we must eliminate contamination from physiologic motions. We can diagnose hemorrhage-containing cysts and fat-containing cysts on T1- and T2-weighted images. Apart from these lesions, we believe SSFP diffusion imaging can provide additional information about the contents of a cyst, including...
Fig. 3. Bilateral ovarian endometrial cysts and left functional ovarian cyst in a 35-year-old female
(a) A T₁-weighted spin-echo (TR = 500 ms, TE = 12 ms) axial image showed bilateral ovarian endometrial cysts (arrows) as markedly high signal intensity lesions with multiplicity. (b) The signal intensities of these endometrial cysts decreased on a T₂-weighted turbo spin-echo (TR = 3500 ms, TE eff = 100 ms/echo train length = 11) axial image with fat saturation. The left ovarian functional cyst (arrow) and ascites (star) were depicted as a high signal intensity area on a T₂-weighted image and a low signal intensity area on a T₁-weighted image. (c) SSFP diffusion image (TR = 30 ms, flip angle = 50°) with short diffusion pulse length (δ = 1 ms). Signal intensities of endometrial cysts, the functional cyst and ascites on this image were similar on the T₂-weighted image. (d) SSFP diffusion image (TR = 30 ms, flip angle = 50°) with medium diffusion pulse length (δ = 8 ms). Signal intensities of endometrial cysts were low, and the signal intensities of the left ovarian functional cyst and ascites became as low as that of muscle. (e) Calculated relative apparent diffusion coefficient (rADC) image. The signal intensity of the SSFP diffusion image with a short diffusion pulse length (δ = 1 ms) was divided by that of the SSFP diffusion image with a long diffusion pulse length (δ = 12 ms), and a logarithmic expression was made. In this image, the signal intensities of the endometrial cysts were low, which indicated low rADC. However, the left ovarian functional cyst and ascites showed high signal intensity, indicating high rADC.
malignant potential.

The calculation of the \( rADC_L/rADC_F \) ratio requires diffusion imaging with two different \( \delta \) values, while the DRC is calculated from diffusion imaging with three or more \( \delta \) values. The present findings showed similar tendencies in the assessment of the DRC and the \( rADC_L/rADC_F \) ratio. Therefore, the \( rADC_L/rADC_F \) ratio is easy to use clinically.

**Conclusion**

SSFP diffusion imaging with only a short scan time can be used in clinical practice for the analysis of ovarian cystic lesions. The DRC and the \( rADC_L/rADC_F \) ratio are useful for evaluating the contents of ovarian cystic lesions. The present findings show that endometrial cysts and the fatty part of dermoid cysts exhibit low DRC and significantly low \( rADC_L/rADC_F \) ratios. However, some overlap was seen in the values of the DRC and \( rADC_L/rADC_F \) ratios between mucinous cystic tumors and serous cystic tumors. It is hypothesized that the presence of hemorrhage or malignant lesions might affect these values.

**Acknowledgments**

The authors wish to thank Takashi Ueda, MT, Akio Tsuji, RT, Kazuo Iwaya, MT, and Masato Uchikoshi, RT, for their data acquisition and assistance with data analysis.

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