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Diffusion-weighted Imaging of Ovarian Torsion: Usefulness of Apparent Diffusion Coefficient (ADC) Values for the Detection of Hemorrhagic Infarction

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Purpose: We undertook this study to evaluate the need for diffusion-weighted (DW) magnetic resonance (MR) imaging in detecting hemorrhagic infarction following ovarian torsion.

Methods: The study included 14 consecutive patients aged 12 to 74 years (average age, 36 years) with surgical confirmation of ovarian torsion who underwent 1.5-tesla MR imaging. Pathologically, hemorrhagic infarction was found in 7 patients. We retrospectively reviewed signal intensity on T₁-, T₂-, and diffusion-weighted images and apparent diffusion coefficients (ADCs) in swollen ovarian stroma.

Results: Fallopian tube thickening was seen in all patients. In patients with ovarian cystic lesion, maximum cyst wall thickness was significantly higher in patients with hemorrhagic infarction (mean, 13.5 ± 4.1 mm) than those without (mean, 5.0 ± 1.0 mm) ($P < .05$). Signal intensity did not differ significantly on T₁-weighted, T₂-weighted, and DW images between patients with and without hemorrhagic infarction. ADCs were significantly lower in patients with hemorrhagic infarction ($1.20 \pm 0.50 [\times 10^{-3} \text{ mm}^2/\text{s}]$) than those without ($2.04 \pm 0.26 [\times 10^{-3} \text{ mm}^2/\text{s}]$) ($P < .01$). With an ADC threshold of $1.80 [\times 10^{-3} \text{ mm}^2/\text{s}]$, sensitivity for hemorrhagic infarction was 0.88 (7 of 8), and specificity was 1.00 (6 of 6).

Conclusion: ADC measurements were useful for detecting hemorrhagic infarction in patients with ovarian torsion.

Keywords: *apparent diffusion coefficient, diffusion-weighted imaging, hemorrhagic infarction, ovarian torsion*

Introduction

Ovarian torsion is an uncommon cause of lower abdominal pain in women and accounts for 2.7% of all gynecological surgical emergencies.¹ It can occur at any age but is most common during reproductive age. Approximately 60% of cases occur on the right side, perhaps because the colon occupies pelvic space on the left or because of the hypermobility of the cecum and distal ileum on the right. Although more than half of patients with ovarian torsion have accompanying ipsilateral ovarian tumor or cyst, nor-

mal ovaries may also undergo torsion, especially in children with mobile ovaries caused by long mesovaria.² Early diagnosis enables conservative laparoscopic treatment and reduces complications. However, diagnosis is delayed in most cases because the preoperative diagnosis of ovarian torsion is difficult due to nonspecific clinical and laboratory findings, and this often results in infarction and necrosis of the ovary.

Furthermore, circulatory stasis resulting from torsion of the ovarian pedicle is initially venous but eventually becomes arterial and results in the progress of edema.³ If torsion is complete and the arterial blood supply is obstructed, gangrenous and hemorrhagic necrosis occurs. Thus, when complete

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torsion is suspected, immediate surgery is necessary to remove damaged tissue. If left untreated, hemorrhagic infarction of the involved ovary may be followed by infection, rupture, peritonitis, adhesion, and, in some cases, death. However, although swift laparoscopic detorsion may allow salvage of a viable ovary without critical complications, the salvage rate has been reported to be below 10% in adults but as high as 27% in children.⁴ Therefore, the preoperative recognition of hemorrhagic infarction following ovarian torsion is critical for preemptive surgical treatment.

Conventional computed tomography (CT) and magnetic resonance (MR) imaging are known to detect hemorrhage in thickened Fallopian tubes or within torsed ovarian masses and hemoperitoneum in patients with ovarian torsion accompanied by hemorrhagic infarction. However, these imaging findings have low sensitivity for hemorrhagic infarction despite their high specificity.² On the other hand, diffusion-weighted (DW) MR imaging allows the semiquantitative evaluation of molecular diffusion caused by random molecular motion (Brownian motion) and has proven highly sensitive for the early detection of cytotoxic (cellular) edema and hemorrhage. Accordingly, the purpose of this study was to assess if DW MR imaging is necessary for the evaluation of ovarian torsion, with emphasis on the detection of hemorrhagic infarction.

Materials and Methods

Patients

The study was approved by the human research committee of our institutional review board and complied with the guidelines of the Health Insurance Portability and Accountability Act. The requirement for informed consent was waived because of the study's retrospective nature. We searched the electronic medical chart system of Gifu University Hospital between April 1 and November 30 for patients with surgically confirmed ovarian torsion. We identified 16 patients, 14 (age range, 12 to 74 years; average age, 36 years) of whom underwent preoperative MR imaging including DW imaging with a 1.5-tesla MR imager.

All 14 patients complained of lower abdominal pain; onset was acute in seven and gradual in seven. Time between MR imaging and surgery ranged from 0 to 34 days (mean, 8.4 ± 11.4 days). Ovarian torsion occurred in the right side in 10 patients (71%) and in the left in four (29%). The sizes of torsed ovarian lesions ranged from 40 to 188 mm (mean, 97 ± 41 mm), and degree of ovarian rotation ranged from 180° to 1440° (mean, $463^\circ \pm 321^\circ$). Severe

hemorrhagic infarction of the torsed ovary was pathologically found in 7 (50%) of the 14, and the diseased ovary could be salvaged in a viable state in 6 patients without hemorrhagic infarction. No patient had a ruptured torsed ovary. All patients had an ipsilateral benign ovarian lesion, and the histopathologic diagnoses were mature cystic teratoma ($n = 4$), serous cystadenoma ($n = 3$), mucinous cystadenoma ($n = 2$), normal ovary ($n = 2$), endometrial cyst ($n = 1$), polycystic ovary syndrome ($n = 1$), and undetermined cystic lesion ($n = 1$).

MR imaging

MR imaging was performed using a 1.5T MR imaging system (Intera Achieva 1.5T Pulsar, Philips Medical Systems, The Netherlands) with a phased-array body coil to allow whole pelvic coverage. All images were obtained in the transverse plane using parallel imaging at a section thickness of 5 mm with 2-mm intersection gap and 28×28 -cm field of view. Non-fat-suppressed T_1 -weighted spin-echo (repetition time [TR]/echo time [TE], 607 to 680 ms/10 to 15 ms; 512×512 matrix) and non-fat-suppressed T_2 -weighted fast spin-echo (TR/TE, 4,415 to 6,263 ms/90 to 100 ms; 512×512 matrix) images were obtained for all 14 patients. No patient underwent gadolinium-enhanced MR imaging.

DW images (TR/TE, 4,000 ms/60 ms; 256×256 matrix) were obtained for all patients using a single-shot spin-echo echo-planar imaging sequence using b -values of 0 and $1,000 \text{ s/mm}^2$. Motion-probing gradients of the same strength were placed in the 3 orthogonal directions. Acquisition time for DW imaging was 136 s.

MR image data analysis

A radiologist with 12 years of post-training experience in interpreting genitourinary images who was unaware of patient history and pathologic information reviewed all images for the presence of Fallopian tube thickening, smooth wall thickening of the torsed ovarian cystic lesion, uterine deviation to the torsed side, and hemoperitoneum. The presence of Fallopian tube thickening was determined in comparison with the opposite side.

In addition, the same reviewer measured signal intensity and apparent diffusion coefficient (ADC) values on images using regions of interest (ROIs) of round or oval shape placed in swollen ovarian stroma located at the periphery of cystic lesions or between multiple peripheral follicles. ROIs were placed to encompass swollen ovarian stroma as much as possible with care taken to avoid cystic components and in reference to T_2 -weighted images. The reviewer also measured the signal intensity of

Table 1. Conventional magnetic resonance (MR) imaging findings suggestive of ovarian torsion

MR imaging findings	With hemorrhagic infarction (<i>n</i> = 7)	Without hemorrhagic infarction (<i>n</i> = 7)
Fallopian tube thickening	7 (100%)	7 (100%)
Smooth wall thickening of the torsed ovarian cystic lesion	4 (67%)*	3 (50%)*
Maximum cyst wall thickness (mm)		
Mean	13.5 ± 4.1**	5.0 ± 1.0
Range	8–18	4–6
Uterine deviation to the twisted side	2 (29%)	4 (57%)
Hemoperitoneum	3 (43%)	0 (0%)

*Six had cystic lesions in the torsed ovary.

**Value is significantly greater than with torsed ovary without hemorrhagic infarction.

Table 2. Quantitative results in patients with and without hemorrhagic infarction

	With hemorrhagic infarction (<i>n</i> = 7)	Without hemorrhagic Infarction (<i>n</i> = 7)	<i>P</i> value
T ₁ -weighted	1.93 ± 0.63*	1.34 ± 0.20	0.053
T ₂ -weighted	0.70 ± 0.31	0.92 ± 0.25	0.159
Diffusion-weighted	3.61 ± 2.85	1.68 ± 0.28	0.123
ADC (× 10 ⁻³ mm ² /s)	1.20 ± 0.50**	2.04 ± 0.26	0.004

Values are mean ± one standard deviation of ovarian stroma-to-urine signal intensity ratios with T₁-, T₂-, and diffusion-weighted images and apparent diffusion coefficients (ADCs).

*Value is marginally greater than with torsed ovary without hemorrhagic infarction.

**Value is significantly lower than with torsed ovary without hemorrhagic infarction.

urine in the bladder to obtain ovarian stroma-to-urine signal intensity ratios. ADCs [× 10⁻³ mm²/s] were calculated using 2 *b* factors (0 and 1000 s/mm²) and measured on ADC maps in ROIs placed in swollen ovarian stroma.

Statistical analysis

Statistical analysis was performed using SPSS version 18.0 software (SPSS, Inc, an IBM Company, Chicago, IL, USA). We used unpaired *t*-test to compare maximum cyst wall thickness, signal intensity ratios (T₁-weighted, T₂-weighted, and DW images), and ADCs between patients with and without hemorrhagic infarction. *P* < 0.05 was considered significant.

Results

Table 1 summarizes conventional MR imaging findings of ovarian torsion. Fallopian tube thickening was observed in all patients. Smooth wall thickening of the torsed ovarian cystic lesion was observed in 4 (67%) patients with hemorrhagic infarction and 3 (50%) patients without. Maximum cyst wall

thickness was significantly greater in patients with hemorrhagic infarction (mean, 13.5 ± 4.1 mm) than those without (5.0 ± 1.0 mm) (*P* = 0.019). Uterine deviation to the torsed side was seen in 2 (29%) patients with hemorrhagic infarction and 4 (57%) patients without, and hemoperitoneum was observed in 3 (43%) patients with hemorrhagic infarction and no patient without.

Table 2 summarizes the quantitative results in patients with and without hemorrhagic infarction. Mean ovarian stroma-to-urine signal intensity ratio on T₁-weighted images was marginally higher in patients with hemorrhagic infarction than those without (*P* = 0.053), but no significant difference was found on T₂-weighted or DW images. However, ADCs were significantly lower in patients with hemorrhagic infarction (1.20 ± 0.50 [× 10⁻³ mm²/s]) than those without (2.04 ± 0.26 [× 10⁻³ mm²/s]) (*P* = 0.004) (Figs. 1,2). Using an ADC threshold of 1.80 [× 10⁻³ mm²/s], sensitivity for hemorrhagic infarction was 0.88 (7 of 8), and specificity was 1.00 (6 of 6).

Fig. 1. A 33-year-old woman with ovarian torsion without hemorrhagic infarction. **(a)** Axial T₂-weighted fast spin-echo magnetic resonance (MR) image (repetition time [TR]/echo time [TE], 4,856 ms/100 ms) shows hyperintensity in swollen ovarian stroma (arrow) between the peripheral follicles (arrowheads). The largest cystic lesion (curved arrow) was pathologically diagnosed as serous cystadenoma. **(b)** Axial T₁-weighted spin-echo MR image (TR/TE, 668 ms/10 ms) shows hypointensity in the swollen ovarian stroma (arrow). **(c)** Axial diffusion-weighted MR image (TR/TE, 4,100 ms/90 ms) shows slight hyperintensity in the swollen ovarian stroma (arrow). **(d)** Apparent diffusion coefficient (ADC) map shows increased ADC of the swollen ovarian stroma ($2.03 \times 10^{-3} \text{ mm}^2/\text{s}$). Dotted lines show the contours of the region of interest placed in the swollen ovarian stroma.

Discussion

Although ovarian torsion is often difficult to distinguish from other acute abdominopelvic conditions, its early diagnosis helps prevent irreversible structural damage and may allow conservative ovary-sparing treatment. CT and MR imaging are useful diagnostic tools for ovarian torsion, and their common imaging features include Fallopian tube thickening, smooth wall thickening of the twisted ovarian cystic mass, and uterine deviation to the twisted side.^{2,5,6} Fallopian tube thickening and smooth cystic wall thickening were the common imaging features in the present study.

Early detection of hemorrhagic infarction is es-

sential for appropriate management in patients with ovarian torsion. However, although such imaging findings as hemorrhage in a thickened Fallopian tube or within a torsed ovarian mass and hemoperitoneum have been reported to indicate hemorrhagic infarction of torsed ovaries, the diagnostic performances of radiologic examinations for hemorrhagic infarction has not been determined. Hemoperitoneum on unenhanced CT tended to have high specificity but low sensitivity for diagnosing hemorrhagic infarction of torsed ovary.² Meanwhile, MR imaging has a substantial advantage in terms of depiction of hemorrhagic infarction following ovarian torsion because of its high sensitivity for hemorrhage. However, signal intensity of hemorrhage depends on the

Fig. 2. A 60-year-old woman with ovarian torsion with hemorrhagic infarction. (a) Axial T₂-weighted fast spin-echo magnetic resonance (MR) image (repetition time [TR]/echo time [TE], 5,298 ms/100 ms) shows mixed hypo- (arrow) and hyperintensity (arrowhead) in the swollen ovarian stroma in the periphery of a cystic lesion (curved arrow). The cystic lesion was pathologically undetermined. (b) Axial T₁-weighted spin-echo MR image (TR/TE, 628/10 ms) shows slight hyperintensity (arrow) relative to muscles and hyperintense rim (arrowheads) indicative of hemorrhage in the swollen ovarian stroma. (c) Axial diffusion-weighted MR image (TR/TE, 4,000 ms/60 ms) shows intense hyperintensity in the swollen ovarian stroma (arrow). (d) Apparent diffusion coefficient (ADC) map shows significantly decreased ADC for hemorrhagic necrosis in the swollen ovarian stroma ($0.63 \times 10^{-3} \text{ mm}^2/\text{s}$). Dotted lines show the contours of the region of interest placed on the swollen ovarian stroma.

chemical state of iron (ferrous or ferric) in the hemoglobin molecule and on the integrity of red blood cell (RBC) membranes.⁷

On T₁-weighted images, some torsed ovaries with hemorrhagic infarction showed hyperintensity,^{2,8–10} but others demonstrated hypointensity.^{3,11,12} Furthermore, due to passive congestion, T₁-weighted images depicted a torsed ovary without hemorrhagic infarction as hyperintense.¹³ Methemoglobin generated during the subacute phase of hemorrhage causes shortening of T₁ relaxation time that results in hyperintensity on T₁-weighted images. On the other hand, acute hemorrhage containing oxy- or deoxy-hemoglobin is depicted as iso- or hypointense on T₁-weighted images. Therefore, for the above-mention-

ed reasons, it is often difficult to diagnose hemorrhagic infarction using only T₁-weighted images.

Hyperintensity of enlarged ovarian stroma on T₂-weighted images may indicate an edematous condition in viable torsed ovaries,^{13,14} whereas hypointensity may indicate hemorrhagic infarction.^{3,11,12} In our series, we observed no significant difference in signal intensity ratios on T₂-weighted images between patients with and without hemorrhagic infarction, probably because signal intensity on T₂-weighted images varies during the course of hemorrhage.

Lack of enhancement of the solid components of torsed ovaries may directly indicate interrupted blood flow and facilitate a diagnosis of ovarian tor-

sion.^{2,9} In particular, gadolinium-enhanced dynamic subtraction MR imaging provides confirmation that a tumor is not vascularized, but assessment of the presence of enhancement in thin-walled cystic lesions without solid components is not always straightforward.

A previous study of ovarian torsion found that DW imaging showed abnormal signal intensity in the thickened Fallopian tube and in the wall of cystic ovarian lesions, but unfortunately, they did not assess hemorrhagic infarction.¹⁵ One case report describing DW imaging findings in a patient with ovarian torsion and hemorrhagic infarction found an ADC value of torsed ovarian stroma as low as $0.94 \times 10^{-3} \text{ mm}^2/\text{s}$, as we found in the present study.¹⁶ In a study reporting findings in the testes of experimental rats 2 hours after funicular ligation, ADCs were 20% lower than those in nonischemic contralateral testes, whereas no significant difference in signal intensity was found between ischemic and normal testes on T₂-weighted images.¹⁷ The authors of that report suggested the usefulness of DW imaging for the detection of the early phase of ischemia secondary to acute testicular torsion. Meanwhile, diffusion of water is significantly restricted in early intracranial hematomas in comparison with both late hematomas and normal white matter.¹⁸ Therefore, we infer that cytotoxic (cellular) edema and hemorrhage in torsed ovarian stroma with hemorrhagic infarction in the present study caused restricted diffusion and, thus, low ADCs, as the previous authors observed with testicular torsion.

Our study has several limitations. The study population was relatively small because we evaluated findings at one institution; only a single radiologist assessed MR images; and no patient underwent gadolinium-enhanced MR imaging because of the limited examination time available before possible surgical interventions. However, we believe that gadolinium-enhanced MR imaging might be useful for evaluating intraovarian necrosis.

Conclusion

Summarizing, although we found no significant difference in signal intensity ratios on T₁-, T₂-, or diffusion-weighted images between patients with and without hemorrhagic infarction, ADCs were significantly lower in patients with ovarian torsion with hemorrhagic infarction than those without. In addition, high sensitivity and specificity for hemorrhagic infarction were calculated using an ADC threshold. These results indicate the utility of ADC measurements for detecting hemorrhagic infarction in patients with ovarian torsion.

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