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Clinical Usefulness of Diffusion-weighted Imaging Using Low and High b-values to Detect Rectal Cancer

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Purpose: The purpose of this study was to assess the potential role of diffusion-weighted imaging (DWI) using low and high b-values to detect rectal cancer.

Methods: The subjects were 15 patients diagnosed endoscopically with rectal cancer (*m* in 1 patient, *sm* in 0, *mp* in 3, *ss* in 7, *se* in 1, *a* in 3) and 20 patients diagnosed endoscopically with colon cancer and no other lesions (control group). Magnetic resonance imaging was performed using a 1.5T system. DWI was performed in the axial plane using echo planar imaging sequence (repetition time/echo time 1200/66, field of view 306 × 350 mm, reconstruction matrix 156 × 256, pixel size 2.0 × 1.4 × 8.0 mm) and acquired with 2 b-values (50 and 800 s/mm^2). Low and high b-value DW images were analyzed visually. A lesion was positive by detection of a focal area of high signal in the rectum in high b-value images. The apparent diffusion coefficient (ADC) values of areas of high signal in high b-value images were calculated from the low and high b-value images.

Results: High b-value images enabled visualization of all 15 rectal cancers. In the control group, 13 cases were classified as negative and 7 cases as positive for rectal cancer. Sensitivity for detection of rectal cancer was 100% (15/15), and specificity was 65% (13/20). The mean ADC values in 7 patients with false-positive lesions and in 15 patients with rectal cancer were 1.374×10^{-3} mm^2/s (standard deviation [SD]: 0.157) and 1.194×10^{-3} mm^2/s (SD: 0.152), respectively ($P = 0.026$).

Conclusion: DWI with low and high b-values may be used to screen for rectal cancer.

Keywords: *diffusion-weighted images, low and high b-value, rectal cancer*

Introduction

Diffusion-weighted imaging (DWI) is a new magnetic resonance (MR) imaging technique that evaluates the diffusion capacity of water molecules and supplements conventional MR imaging; its clinical usefulness in the acute stage of cerebral infarction has been confirmed.[1–4] Moreover, advances in MR imaging in recent years have enabled stable DWI even in the trunk region, and DWI's usefulness for detecting malignant tumors has been explored.[5–9] One study evaluated use of high b-value while maintaining high image resolution under free breathing.[10] We used respiratory triggering to assess detailed anatomical information and investigated the potential role of DWI using low and high b-values to detect rectal cancer.

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Materials and Methods

Patients

The subjects were 15 patients diagnosed endoscopically with rectal cancer and 20 patients diagnosed endoscopically with colon cancer with no other lesions (control group; cecal cancer, 2 patients; ascending colon cancer, 5; transverse colon cancer, 5; descending colon cancer, 2; and sigmoid colon cancer, 6). DWI was performed in all patients 3 to 22 days (mean = 11) before surgery.

Fifteen consecutive patients with rectal cancer (11 men, 4 women; aged 31 to 81 years, mean age 64.2) and a control group of 20 consecutive patients (16 men, 4 women; aged 51 to 81 years, mean age 64.9) underwent DWI between June and December 2005.

The size of rectal cancers ranged from 11 mm × 5 mm to 250 mm × 100 mm (mean: 53.9 mm × 32.9 mm), and the stage of cancer progression was *m* in 1 patient, *sm* in 0 patient, *mp* in 3 patients, *ss* in 7 patients, *se* in 1 patient, *a1* in 2 patients, and *a2* in 1 patient. Tumors were well differentiated in 2 patients and moderately differentiated in 13 patients. Stage of cancer progression and tissue differentiation were recorded according to the Japanese *Guidelines for the Clinical and Pathological Studies of Colorectal Cancer*.[11]

Institutional Review Board approval was not required because the study was retrospective.

Imaging protocol

MR imaging was performed using a 1.5T system (MAGNETOM Avanto: SIEMENS AG Medical Solutions, Erlangen, Germany; maximum gradient field strength, 30 mT/m). All patients were examined in a supine position using a body and spine matrix coil. Abdominal and pelvic examination consisted of T_1-weighted, T_2-weighted, and DW imaging that could be done in one session.

In all patients, T_1-weighted, T_2-weighted, and DW images were obtained in the axial plane. In addition, T_2-weighted images were obtained in the sagittal plane. T_1-weighted images (gradient echo; repetition time/echo time [TR/TE] 105/4.76; flip angle 75°; average 1; bandwidth 300 Hz/pixel) and T_2-weighted images (fast spin echo; TR/TE 3000/90; average 1; bandwidth 200 Hz/pixel) were obtained with slice thickness 8 mm; section gap 2 mm; field of view (FOV) 380 × 380 mm; and matrix 256 × 320.

DWI was performed in the axial plane using echo planar imaging (EPI) sequence with the following parameters: TR/TE 1200/66; field of view 306 × 350 mm; acquisition matrix 78 × 128; reconstruction matrix 156 × 256 (with zero-fill interpolation); reconstruction pixel size 2.0 × 1.4 mm; receiver bandwidth 3,004 Hz/pixel; slice thickness 8 mm; section gap 1.6 mm; number of slices 24, average 6; and PAT mode generalized autocalibrating partial parallel acquisition (GRAPPA) factor 2, which makes acquired echo train length 39. DWI trace images were acquired with motion-probing gradient (MPG) pulses applied in 3 directions with b-values of 50 and 800 s/mm^2. Acquisition time was 3 to 4 min. Fat saturation was used to avoid severe chemical shift artifact from fat. Scanning was performed with respiratory triggering. Antispasmodics or cathartic agents were not administered before scanning.

Imaging analysis

Images were evaluated retrospectively by 2 diagnostic radiologists (TH and MT) blinded to

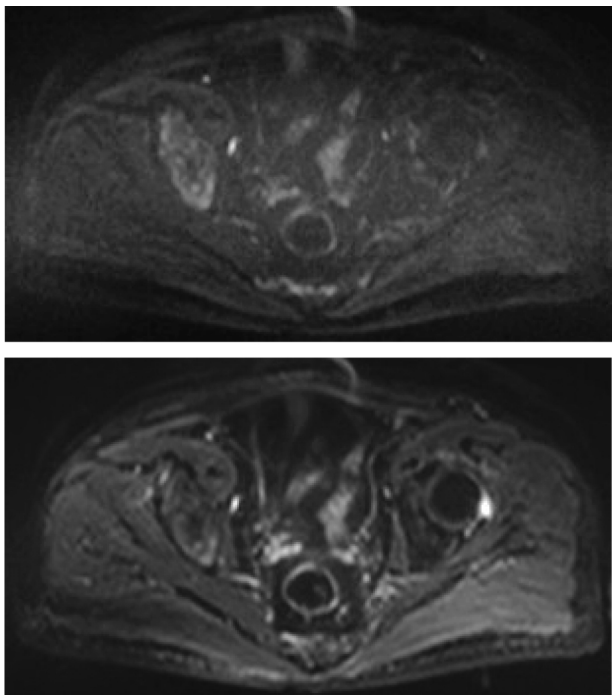

Fig. 1. 78-year-old man with a transverse colon carcinoma
a. high b-value (WW/WL: 82/30); **b**. low b-value (WW/WL: 181/44). There was no area of high signal in the rectum in high b-value images; this is therefore classified as negative.

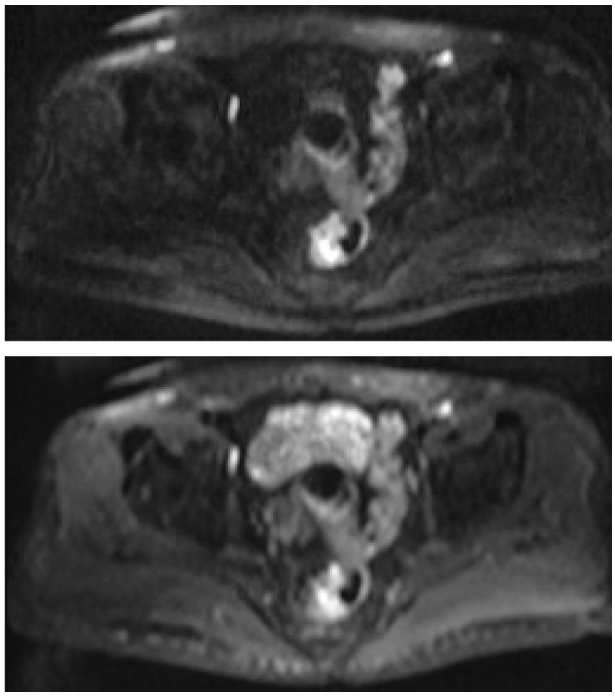

Fig. 2. 65-year-old man with a rectal carcinoma
a. high b-value (WW/WL: 112/42); **b**. low b-value (WW/WL: 250/92). There was an area of high signal in the rectum in high and low-b value images; this is therefore classified as positive. The apparent diffusion coefficient (ADC) value is 1.229×10^{-3} mm^2/s.

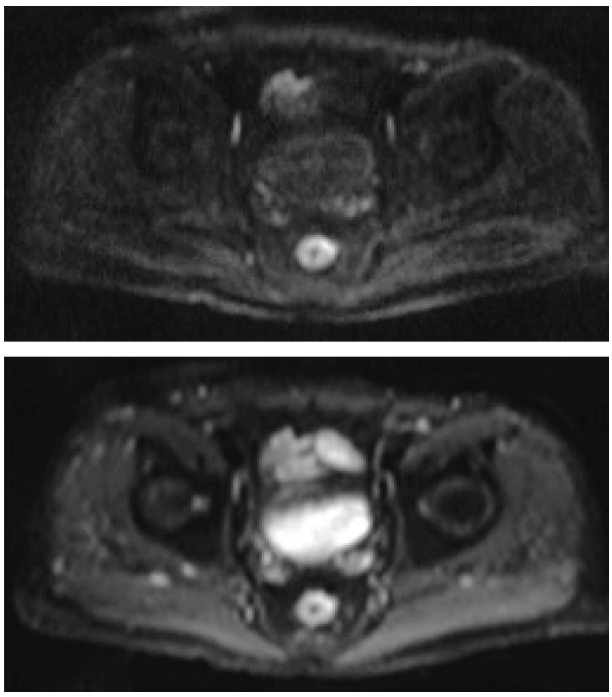

Fig. 3. 74-year-old man with a cecal carcinoma
a. high b-value (WL/WW: 89/34); **b**. low b-value (WL/WW: 287/104). A full-circumference (ring-shaped) area of high signal is seen in the rectum in high and low-b value images (false-positive). The apparent diffusion coefficient (ADC) value is 1.337×10^{-3} mm^2/s.

whether the patients had rectal cancer, the morbidity prevalence of the subjects, or the pathological diagnosis. Each case was randomly selected from a pool of all 35 cases before review. Radiological diagnosis was reached upon agreement of the radiologists.

Low (50 s/mm^2) and high b-value (800 s/mm^2) DWI were visually analyzed. A lesion was defined as positive if a focal area of high signal was detected in the rectum in high b-value images (Figs. 1–3).

The apparent diffusion coefficient (ADC) values of areas of high signal in high b-value images were calculated from the low and high b-value images. All ADC values were calculated according to the formula: $ADC = [\ln (S_h/S_l)]/(b_h - b_l)$, where S_h and S_l are the signal intensities in the region of interest (ROI), obtained with low and high b-values (50 and 800 s/mm^2, respectively).

Statistical analysis

ADC values were analyzed by Mann-Whitney *U*-test, and *P*-value less than 0.05 was considered statistically significant.

Results

High b-value images enabled visualization of all 15 rectal cancers. In the control group, 13 cases were classified as negative and 7 cases as positive for rectal cancer (Table 1). Sensitivity to detect rectal cancer was 100% (15/15); specificity was 65% (13/20). In 3 cases among 7 patients with false-positive lesions, the lower rectum was visualized as a full-circumference (ring-shaped) area of high signal intensity (Fig. 3).

Table 1. Detectability of rectal cancer in high b-value images

Group	Nagative	Positive
Control group	13	7
Rectal cancer	0	15

Sensitivity for detection of rectal cancer was 100% (15/15); specificity was 65% (13/20).

Table 2. Mean apparent diffusion coefficient (ADC) values

Lesions	No. of patients	Mean ADC value (mm^2/s)
False-positive lesions	7	1.374×10^{-3} (SD: 0.157)
Rectal cancer	15	1.194×10^{-3} (SD: 0.152)

*p = 0.026, Mann-Whitney *U*-test.

Table 2 shows the ADC values of the areas of high signal in high b-value images. The mean ADC values in 7 patients with false-positive lesions and in 15 with rectal cancer were 1.374×10^{-3} mm^2/s (SD 0.157) and 1.194×10^{-3} mm^2/s (SD 0.152), respectively ($P = 0.026$).

Discussion

In 1975, the number of deaths per annum from colorectal cancer in Japan was about 5,000. By 2001, however, it rose to approximately 37,000 (29.3 per 100,000 population), accounting for 12% of all cancer deaths. Colorectal cancer ranked as the fourth highest cause of death from malignant tumors in men and the second in women.

Fecal occult blood, measurement of tumor markers, and rectal examination are simple and convenient methods of screening for rectal cancer. Further means of detecting cancer include visualizing lesions by colonoscopy and performing radiological investigations, i.e. barium enemas, computed tomography (CT), and MR imaging scans. Diagnostic imaging of colorectal cancer can be used for initial detection and for qualitative diagnosis of lesions.

Barium enema and colonoscopy play major roles

in initial detection. CT has been reported to provide a low detection rate, and many lesions it detects are already highly advanced cases.[12–14] CT colonography has attracted interest in recent years and is expected to become clinically useful for diagnosing colorectal cancer. For example, it has been reported to enable diagnosis of superficially depressed tumors (Type IIc in the classification by Japanese Society for Cancer of the Colon and Rectum),[11] which are considered difficult to diagnose.[15–17] Disadvantages, however, are its invasive nature and the need for patient preparation before scanning, just like that for barium enema or colonoscopy. MR imaging seems a promising alternative for these well-known investigations because patient preparation is not required, there is no risk of radiation exposure, and it is noninvasive.

The clinical usefulness of DWI has been established in patients with cerebral infarction in the acute stage.[1–4] Lesions are depicted as areas of high signal because their ADC values are lower than in normal tissue. This decrease in ADC value is thought to result from an increase in the number or size of the cells; as a result, intercellular spaces become smaller, restricting movement of water molecules present in the intercellular spaces.[18] Development of high magnetic field homogeneity and powerful gradient magnetic field coils in recent years has made it possible to obtain images with a high signal-to-noise (S/N) ratio, even with a high b-value. Thus, DWI's usefulness for detecting malignant tumors in the abdominal region has now been studied by many researchers.[5–10]

Because of its ability to delineate soft tissues, MR imaging in rectal cancer has been used more in detecting spread of disease than for initial diagnosis.[14,19–21] However, if we could use DWI to detect malignant tumors in the gastrointestinal region, it is hoped that MR examination will become the imaging modality of choice for initial detection of tumors as well as the study of disease spread.

In the present study, DW images were taken using low and high b-values. Using high b-value images, sensitivity for detection of rectal cancer was 100% (15/15) and specificity was 65% (13/20). Therefore, if the detection of lesions is the primary purpose of DWI, it may be used with high b-values as a screening tool for rectal cancer. However, its sensitivity must not be diminished, which inevitably results in over-diagnosis of lesions in many cases (7/20). On the other hand, the mean ADC values in 7 patients with false-positive lesions and in 15 with rectal cancer were 1.374×10^{-3} mm^2/s and 1.194×10^{-3} mm^2/s, respectively. This showed that the ADC values in rectal cancer were significantly lower than those in benign areas of high signal. After high b-value images were assessed visually, the evaluation of ADC values calculated from the low and high b-value images could be useful for differentiating benign and malignant lesions.

Nasu's group reported that on SENSE-DWI with b-value of 1000 s/mm^2, normal colon wall and feces were always hypointense and easily differentiated from tumors. They also reported the mean ADC value of each tumor as $1.02 \pm 0.1(\times 10^{-3})$ mm^2/s.[22] In the present study, high b-value was set at 800 s/mm^2. Setting the high b-value at 1,000 s/mm^2 and using the ADC values for evaluation may allow fewer false-positive cases.

In 3 normal cases evaluated as positive in this study, the lower rectum was visualized as a full-circumference (ring-shaped) area of high signal (Fig. 3). Because pathological exploration was not performed at the site, the cause of such ring-shaped signals is unknown. However, recognizing this combination of false-positive site (lower rectum) and its morphology (ring-shaped high signal) as specific findings will become important in preventing over-diagnosis of rectal cancer.

Although this study suggested the usefulness of DWI for detecting rectal cancer, it was limited by the small number[15] of cases with rectal cancer, 93% (14/15) of which were advanced, and the absence of histopathological exploration in the false-positive cases. Thus, future study will require inclusion of early-stage cancer, a greater number of cases, and detailed histopathological assessment. Ultimately, a prospective study of the entire large intestine that includes comparisons with other imaging methods will be necessary to strengthen findings of this study.

Conclusion

We evaluated the potential role of DWI using low and high b-values to detect rectal cancer. On DWI using high b-value images, sensitivity for detection of rectal cancer was 100% (15/15) and specificity was 65% (13/20). The ADC values calculated from the low and high b-value images could be useful in differentiating benign and malignant lesions. DWI using low and high b-values may be used to screening for rectal cancer.

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