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Assessment of Activity of Crohn Disease by Diffusion-Weighted Magnetic Resonance Imaging

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Abstract: To assess the diagnostic efficacy of diffusion-weighted MR imaging (DWI) for evaluating inflammatory activity in patients with Crohn's disease (CD). A total of 47 CD patients underwent MR enterography (MRE) and DWI using 3 b values of 50, 400, and 800 s/mm.^{2} Apparent diffusion coefficients (ADCs) of inflamed and normal bowel wall were calculated. The conventional MRE findings and DWI signal intensities were qualitatively scored from 0 to 3. The correlation between Crohn disease activity index (CDAI) and both ADCs and magnetic resonance imaging scores was analyzed. Receiver-operating characteristic curve analysis was used to determine the diagnostic accuracy of CD activity. Of the 47 patients, 25 were active CD (CDAI≥150) and 22 were inactive (CDAI<150). Diffusion-weighted MR imaging and MRE + DWI scores of active CD were significantly higher than that of inactive CD (both $P < 0.001$). Apparent diffusion coefficients in inflamed segments of active CD were lower than that of inactive CD ($P < 0.001$).The DWI scores ($r = 0.74$, $P < 0.001$), ADCs ($r = -0.71$, $P < 0.001$), MRE scores ($r = 0.54$, $P < 0.001$), and MRE + DWI scores ($r = 0.66$, $P < 0.001$) were all correlated with CDAI. The areas under the receiver-operating characteristics curves for ADCs, DWI scores, MRE scores, and MRE + DWI scores ranged from 0.83 to 0.98. The threshold ADC value of 1.17×10^{-3} mm^2/s allowed differentiation of active from inactive CD with 100% sensitivity and 88% specificity. Diffusion-weighted MR imaging and ADC correlated with CD activity, and had excellent diagnostic accuracy for differentiating active from inactive CD.

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Abbreviations: ADC = apparent diffusion coefficient, AUC = areas under the receiver- operating characteristic curve, CD = Crohn disease, CDAI = Crohn disease activity index, DWI = diffusion-weighted MR imaging, MRE = MR enterography, ROC = receiver-operating characteristics.

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INTRODUCTION

Crohn disease (CD) is a chronic and relapsing inflammatory disorder of the gastrointestinal tract. Accurate evaluation of disease activity is crucial for treatment planning. The evaluation is currently based on a combination of clinical score, such as Crohn disease activity index (CDAI), laboratory indexes, endoscopic, and histologic findings.[1,2] Crohn disease activity index is subjective analysis of symptoms and is commonly used as the reference standard for management. Recently, MR enterography (MRE) is recommended as a new diagnostic tool in the management of CD.[1,2] The lack of ionizing radiation and superior soft tissue resolution are especially beneficial for young patients who require serial examinations. MR enterography not only displays the morphologic changes, but also provides the functional information about the bowel wall. Diffusion-weighted imaging (DWI) has recently been investigated for assessing bowel wall in CD.[3–7] It provides information about the random motion of extracellular water molecules in vivo. The apparent diffusion coefficients (ADCs) allow quantitative analysis of the diffusion characteristics of tissues. Reduced diffusion has been reported in inflamed bowel segments with active CD. Diffusion-weighted imaging was superior to contrast-enhanced magnetic resonance imaging (MRI) for detection of bowel inflammation.[5,8–10] The purpose of this study was to assess the efficacy of DWI for evaluating activity of CD.

MATERIALS AND METHODS

Patients

Between August 2013 and February 2015, 92 consecutive patients with abdominal pain underwent MRE in our institution. A total of 45 patients were excluded because of a final diagnosis other than CD. A total of 47 patients (29 men, 18 women; mean age: 27.9 years; range: 11–57 years) with CD confirmed by standard clinical, endoscopic, and histologic criteria were enrolled in this prospective study. The median course of disease was of 30 months (range: 3–144 months). Thirty patients received oral corticosteroid, anti-inflammatory, and/or anti-TNF-α treatments, the other 17 patients had not received treatment at the time of initial diagnosis. Crohn disease activity index served for clinical activity scoring was tested within 1 week of MRE. Inactive disease was defined as a CDAI <150 and active disease was defined as a CDAI ≥150.[11] The study was approved by the Institutional Ethics Review Board of the first affiliated hospital of Sun Yat-Sen University and written informed consent was obtained from all patients.

Magnetic Resonance Enterography Protocol

Bowel preparation included fasting for 6 to8 hours and oral polyethylene glycol electrolyte solution. The patients ingested 1600 to 2000 mL of 2.5% mannitol solution as oral contrast

1 hour before MRE. A total of 10 mg of raceanisodamine hydrochloride (Minsheng Pharmaceutical Group Co., Ltd., Hangzhou, China) was slowly injected intramuscularly into the buttocks to induce gastrointestinal hypotonia 10 minutes before MRE. The examinations of the abdomen and pelvis were performed using a 3T magnetic resonance system (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) and multichannel phased-array body coils. In addition to axial and coronal breath-held half-Fourier acquisition single-shot turbo spin-echo T2-weighted (HASTE-T2WI, repetition time: 1200 ms, echo time: 87 ms, 320×194 matrix, 4 mm slice thickness, 160° flip angle) and fat-suppressed fast low-angle shot T1-weighted (FS-FLASH-T1WI, 210/2.18 ms, 320×200, 4 mm, 70°) images, axial, and coronal free-breathing DWI was acquired with water-excited single-shot spin-echo echo-planar sequence (5000–5900/73–83 ms, 192×115, or 192×154, 4–5 mm) using 3 b values of 50, 400, and 800 s/mm.^{2} Apparent diffusion coefficients map was generated by using monoexponential model on the scanner console. After intravenous injection of 0.2 mL/kg gadolinium ethoxybenzyl diethylenetriaminepentaacetic acid (Gadopentetate dimeglumine, Beilu Pharmaceuticals, Beijing, China) at a rate of 2 mL/s, coronal dynamic contrast-enhanced fat-suppressed three-dimensional volumetric interpolated breath-hold examination (3D-VIBE, 4.37/1.37 ms, 320×217, 2 mm, 13°) was performed at 15 to 35, 40 to 60, 65 to 85, and 90 to 110 s from the beginning of injection.

Magnetic Resonance Imaging Analysis

The examinations were assessed qualitatively in consensus by 2 abdominal radiologists (C-HS and X-HL), who were blinded to clinical, laboratory, and endoscopic results. On MRE images, bowel wall thickness >3 mm or increased contrast enhancement was considered pathologic.[10,11] The intestinal segments with most marked abnormalities were selected for evaluation of activity of CD including thickness, T2 signal intensity, and enhancement of bowel wall. Mural thickness greater than normal bowel wall (score 0) was scored 1 if the thickness >3 to 5 mm, 2 if >5 to 7 mm, and 3 if >7 mm. Mural enhancement greater than adjacent normal bowel wall (score 0) was scored 1 if the signal intensity was markedly less than arteries, 2 if slightly less, and 3 if equal to arteries in the arterial phase.[3] The mural T2 signal intensity was scored 0 for normal, 1 for dark grey, 2 for light grey, and 3 for grey–white intensities.[3] On DWI using b value of 800 s/mm,^{2} the mural hyperintensities greater than adjacent normal bowel wall (score 0) were scored 1 if they were lower than that of renal cortex, 2 if they were between that of renal cortex and spleen, and 3 if they were similar to or higher than that of spleen (Figure 1). The MRE score was defined as the sum of scores derived from the 3 conventional MRE findings. The MRE + DWI score was defined as the sum of scores derived from MRE score and DWI score.

On the automatically generated ADC maps, 1 radiologist (X-HL) calculated the mean ADCs by manually placing 3 round regions of interest (ROIs) on the areas of thickened bowel wall corresponding to highest signal intensities on DWI without including the intestinal content (Figure 2). The ADCs of the adjacent normal intestinal wall were obtained using the same method. The mean area of the ROI was 12.60 ± 2.60 mm.^{2}

Statistical Analysis

Data were analyzed using statistical software package (SPSS version 13.0; SPSS Inc., Chicago, IL). Apparent diffusion coefficients of the inflamed and normal bowel wall were compared using the paired-samples *t* test. Apparent diffusion coefficients in inflamed segments of active and inactive CD were compared using 2 independent samples *t* test. Diffusion-weighted MR imaging scores of active and inactive CD were compared using Wilcoxon rank sum test. The associations between MRE scores, MRE + DWI scores, and CDAI were evaluated with Spearman rank correlation analysis. The association between ADCs and CDAI was determined using Pearson correlation analysis. The areas under the receiver-operating characteristic (ROC) curves [areas under the receiver-operating characteristics curve (AUCs)] were calculated to determine the diagnostic accuracy of the imaging features, ADCs, and total MRE scores. Interobserver agreement for qualitative parameters

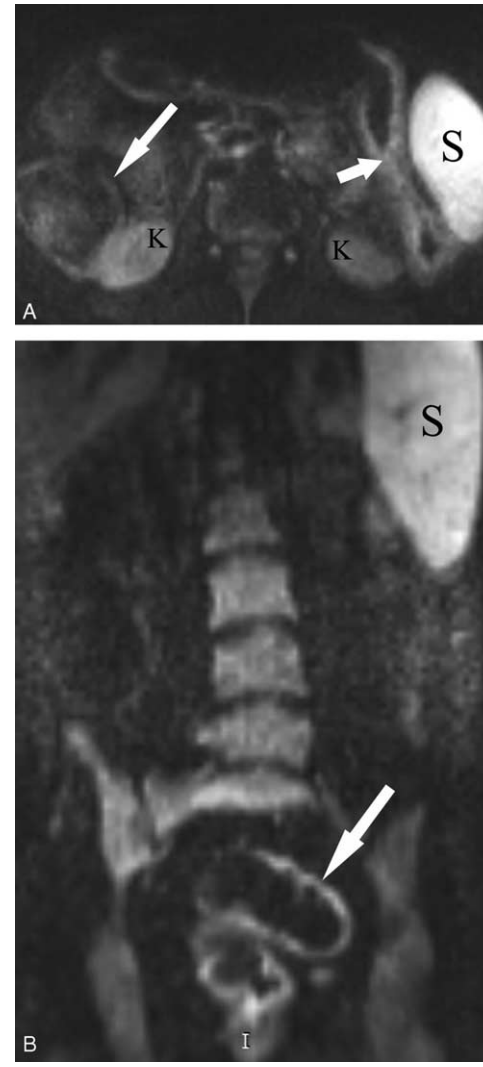

FIGURE 1. The illustration for scoring DWI signal intensity. On axial (A) DWI using b value of 800 s/mm^2, the mural hyperintensity of ascending colon (long arrow) was scored 1 for it was lower than that of renal cortex (K); the mural hyperintensity of splenic flexure of colon (short arrow) was scored 2 for it was between that of renal cortex (K) and spleen (S). On coronal DWI (B), the mural hyperintensity of sigmoid colon and rectum (long arrow) was scored 3 for it was similar to that of spleen (S) DWI = diffusion-weighted MR imaging.

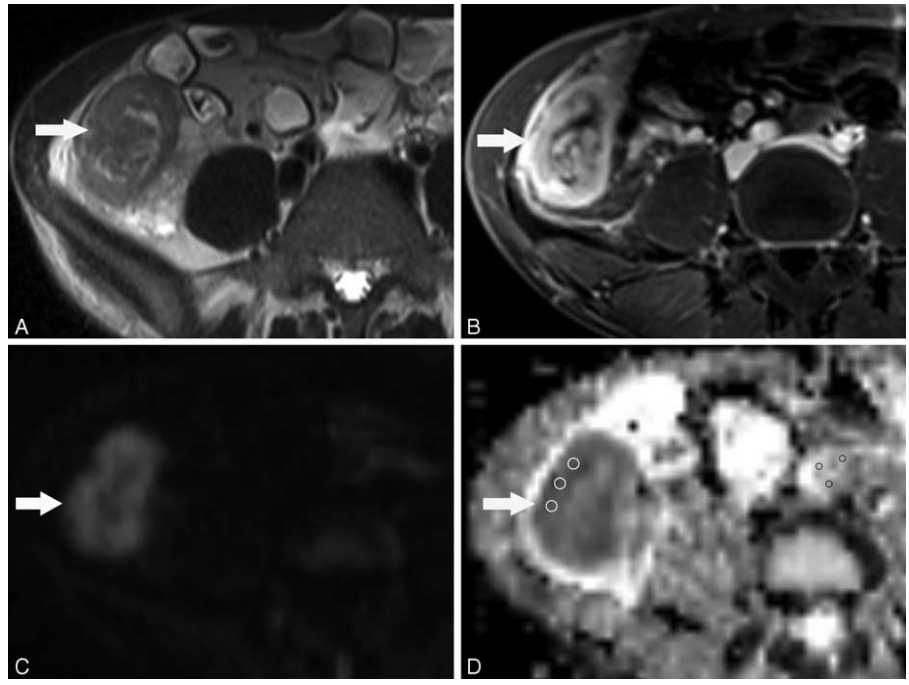

FIGURE 2. A 22-year-old man with active Crohn disease of ascending colon, Crohn disease activity index of 236, MR enterography score of 9, and MRE + DWI score of 12. (A) The axial T2- and (B) contrast-enhanced T1-weighted images show marked mural T2 hyperintensity and contrast enhancement with thickened bowel wall in the ascending colon (arrow). Hyperintensity on the axial diffusion-weighted MR imaging with b = 800 s/mm^2 (C) and hypointensity on corresponding apparent diffusion coefficients map (D) can be seen in the same segment (arrow). The mean apparent diffusion coefficients are calculated from 3 round ROIs in the inflamed bowel wall to be 0.85×10^{-3} mm^2/s (white ROIs) and in the normal bowel wall to be 2.46×10^{-3} mm^2/s (black ROIs). ROI = regions of interest.

was performed with kappa statistics (kappa value $\geq$0.75 was defined as good agreement). All statistical tests were performed 2-sided with significance defined at $P < 0.05$.

RESULTS

Clinical and Magnetic Resonance Enterography Findings

The mean CDAI was 166.93 ± 100.89 (range: 22–380) with CDAI <150 in 22 patients and CDAI ≥150 in 25 patients. The evaluated disease location was ileal or colonic, respectively, in 26 and 21 patients. The bowel segments enrolled in this study were all well distended. The MRE findings with corresponding scores in active and inactive CD were summarized in Table 1. In summary, low scores (score 1–2) were more observed in inactive CD whereas high scores (score 3–4) were more observed in active CD for each MRE findings.

The scores of DWI signal intensity in active CD (median: 3; range: 1–3) were significantly greater than that of inactive CD (median: 1; range: 0–2; $P < 0.001$). The scores of MRE findings in active and inactive CD were shown in Figure 3. The MRE + DWI scores in active CD (median: 9; range: 3–12) were significantly greater than that of inactive CD (median: 5; range: 0–7; $P < 0.001$). The median of MRE scores in 47 patients was 5 with a range of 0 to 9. Good interobserver agreements were obtained for DWI signal intensity (K = 0.76, $P < 0.001$) and enhancement scores (K = 0.78, $P < 0.001$), followed by scores of T2 signal intensity (K = 0.63, $P < 0.001$).

TABLE 1. Magnetic Resonance Enterography Findings in Active (n = 25) and Inactive (n = 22) Crohn Disease Patients

	0		1		2		3	
Score	**Inactive**	**Active**	**Inactive**	**Active**	**Inactive**	**Active**	**Inactive**	**Active**
Mural thickening	(≤3 mm) 6	2	(>3–5 mm) 10	1	(>5–7 mm) 3	4	(>7 mm) 3	18
Mural T2 signal intensity	(Normal) 10	2	(Mild) 9	9	(Moderate) 3	5	(Marked) 0	9
Mural enhancement	(Normal) 3	2	(Mild) 13	7	(Moderate) 3	8	(Marked) 3	8
DWI (b = 800 s/mm^2) signal intensity	(Normal) 7	0	(Mild) 6	2	(Moderate) 9	6	(Marked) 0	17

DWI = diffusion-weighted MR imaging.

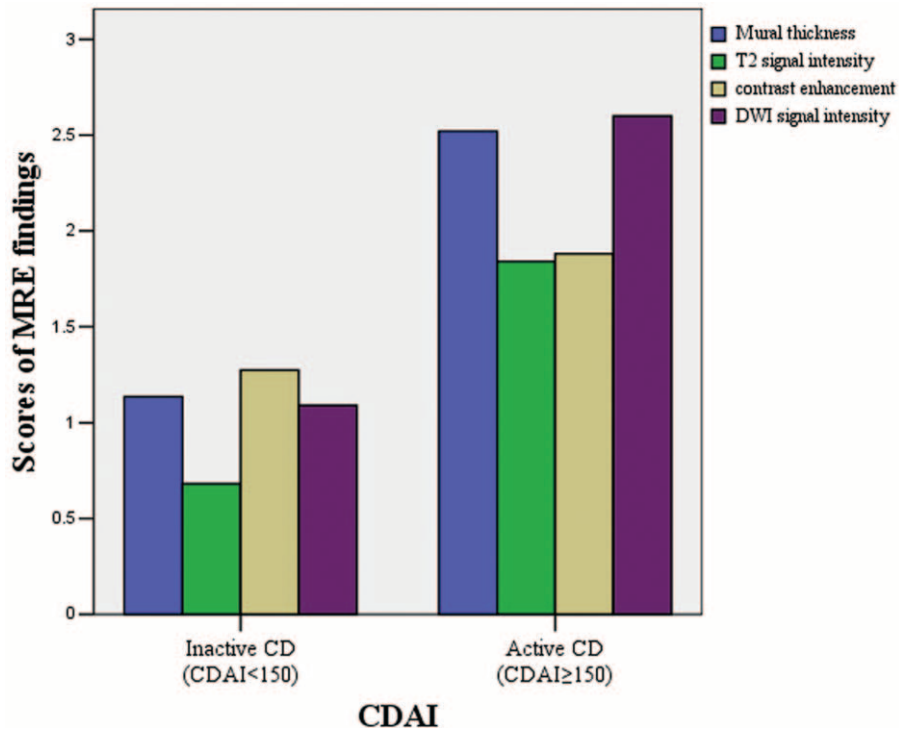

FIGURE 3. The bar chart shows that the scores of MR enterography findings (mural thickness, T2-weighted signal intensity, contrast enhancement and diffusion-weighted MR imaging signal intensity) tend to increase with disease activity.

In 47 patients, the ADCs in inflamed segments ($1.28 \pm 0.47 \times 10^{-3}$ mm^2/s) were significantly lower than that of normal bowel wall ($2.09 \pm 0.27 \times 10^{-3}$ mm^2/s; $P < 0.001$). The ADCs in inflamed segments of active CD ($0.92 \pm 0.18 \times 10^{-3}$ mm^2/s) were significantly lower than that of inactive CD ($1.68 \pm 0.36 \times 10^{-3}$ mm^2/s; $P < 0.001$).

Correlation Analysis

Bivariate correlation indicated a significant positive correlation between the DWI scores and CDAI ($r = 0.74$, $P < 0.001$). There was a significant negative correlation ($r = -0.71$, $P < 0.001$) between ADCs in inflamed segments and CDAI (Figure 4), and no significant correlation ($r = 0.27$, $P = 0.174$) was found between ADCs in normal segments and CDAI. There was significant positive correlation between MRE scores and CDAI ($r = 0.54$, $P < 0.001$) as well as between MRE + DWI scores and CDAI ($r = 0.66$, $P < 0.001$).

RECEIVER-OPERATING CHARACTERISTIC ANALYSIS

Receiver-operating characteristic analysis (Figure 5) showed higher diagnostic accuracy of DWI hyperintensity with AUC of 0.90 ($P < 0.001$) for CD activity than that of bowel wall thickness (AUC = 0.83, $P < 0.001$), T2 hyperintensity (AUC = 0.80, $P < 0.001$), and contrast enhancement (AUC = 0.68, $P < 0.001$). The AUC of ADCs in inflamed segments was significantly higher at 0.98 ($P < 0.001$) with 100% sensitivity and 88% specificity for diagnosing active CD using a threshold ADC value of 1.17×10^{-3} mm^2/s. The AUC of MRE + DWI scores (0.88) was slightly higher than that of MRE scores (0.83) without statistical significance ($P = 0.448$; Figure 6).

DISCUSSION

Diffusion-weighted MR imaging has been used for assessment of activity of CD.[12,13] We also found that the bowel segments of active CD had more markedly reduced diffusion with hyperintensity on high b value DWI and low ADCs than that of inactive CD. The mechanism for the restricted diffusion of water molecules may reduce extracellular space from increased cell density and viscosity, granuloma formation, and dilated lymphatic channels.[5] Qualitative assessment of the bowel wall signal intensity on DWI correlated positively with CDAI, whereas the ADCs correlated inversely with CDAI in our study. No similar correlation was found between ADCs in normal bowel segments and CDAI. The ADCs measured from inflamed bowel wall were significantly lower than normal bowel wall. Diffusion-weighted MR imaging signal intensities increased and ADCs decreased with increasing activity of CD. Receiver-operating characteristics analysis showed higher AUC of DWI using b value of 800 s/mm^2 than that of conventional MRE findings (mural thickness, T2 signal intensities, and enhancement), and ADCs had high AUC of 0.98 for differentiating active from inactive CD. Strong correlation has been reported between MRE scores and disease activity.[1,11] We also found positive correlation between CDAI and MRE scores as well as between CDAI and MRE + DWI scores. Although the AUC was improved without statistical significance after addition of DWI scores to the MRE scores, stronger correlation was shown between CDAI and MRE + DWI scores. The MRE + DWI scores tended to increase with disease activity. There was also significant difference in MRE + DWI scores between active and inactive CD. These results suggested that DWI with ADC analysis may contribute to MRE evaluation of CD activity.

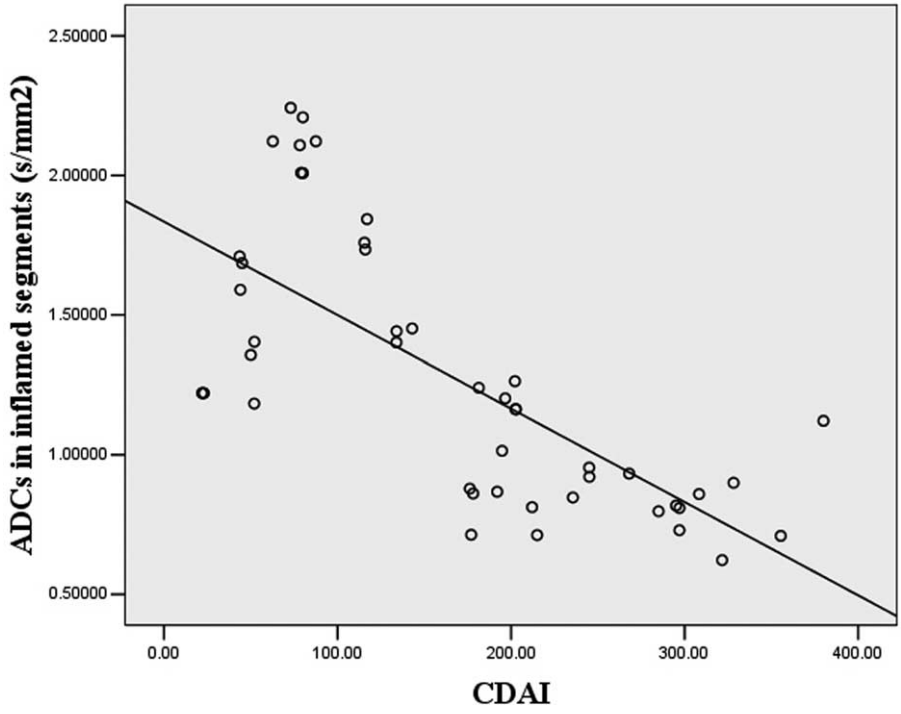

FIGURE 4. Scatter plot of the mean apparent diffusion coefficients in inflamed bowel segments and Crohn disease activity index shows a moderate negative correlation ($r = -0.71$ $P < 0.001$).

The mean ADCs of $1.28 \pm 0.47 \times 10^{-3}$ mm^2/s in inflamed bowel wall in our study were similar to the 1.2×10^{-3} mm^2/s reported by Neubauer et al,[10] but lower than the 1.59×10^{-3} and 1.98×10^{-3} mm^2/s in 2 other studies.[5,8] The differences in ADCs among studies may be related to the different samples and scan parameters including the b values. We used 3 b values of 50, 400, and 800 s/mm^2 whereas 2 b values of 0 and 600 s/mm^2 were used in the 2 literature reports.[5,8] The threshold ADC value for differentiating active from inactive CD is not yet established. In 2 studies, which used 2 b values of 0 and 800 s/

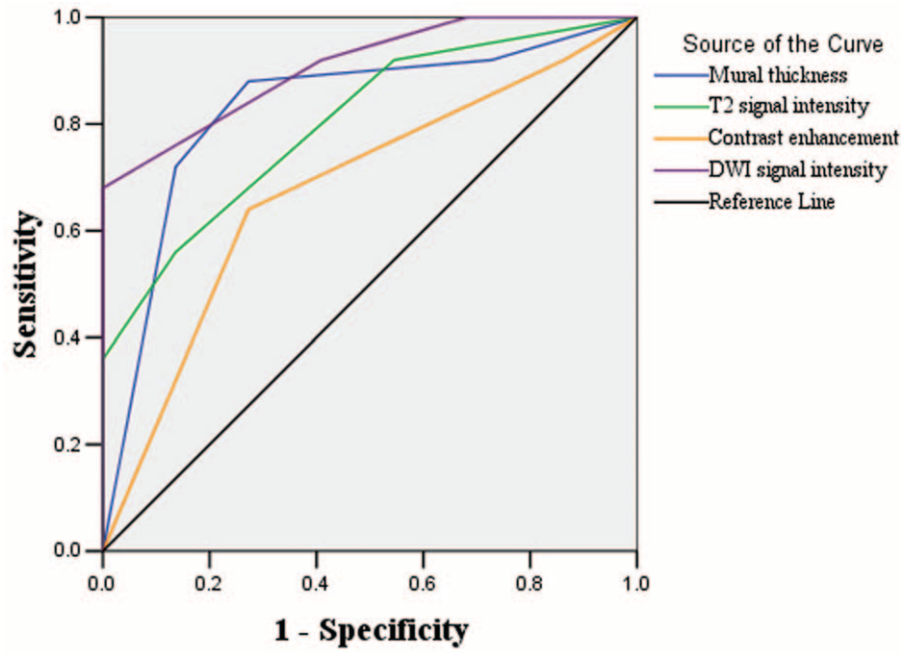

FIGURE 5. Receiver-operating characteristic curves of various radiologic findings show higher areas under the receiver-operating characteristic curve of 0.90 for diffusion-weighted MR imaging signal intensities than that of mural thickness (0.83), mural T2 signal intensities(0.80), and contrast enhancement (0.68) for distinguishing active from inactive Crohn disease.

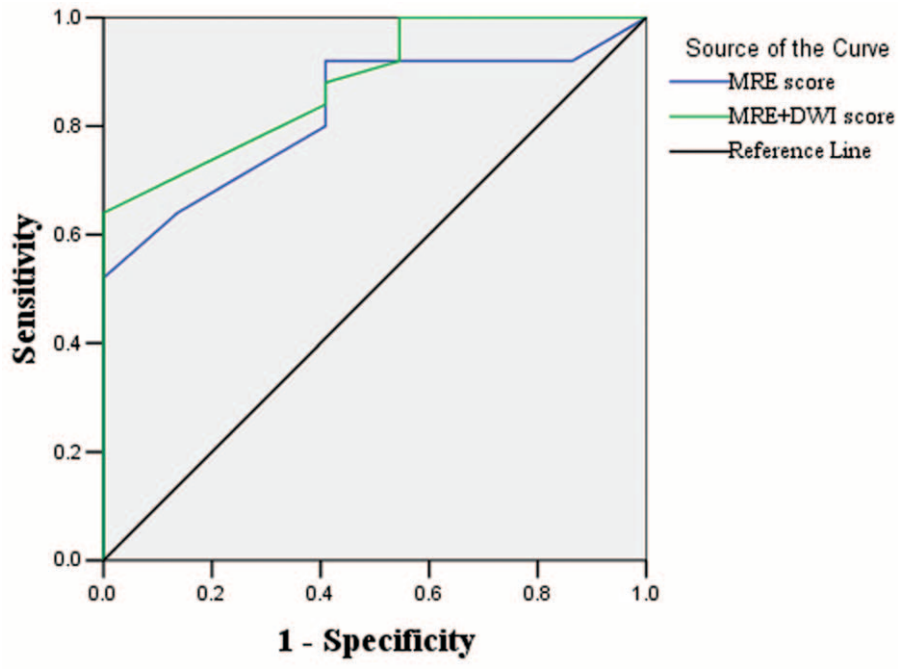

FIGURE 6. Receiver-operating characteristics analysis shows the areas under the receiver- operating characteristics curve of , magnetic resonance enterography + diffusion-weighted MR imaging scores (0.88) was slightly higher than that of magnetic resonance enterography scores (0.83) without statistical significance.

mm^2 and took magnetic resonance index of activity as reference standard,[12,13] a threshold ADC of $1.6 \times 10^{-3}\,mm^2/s$ had a diagnostic sensitivity of 82.4% and specificity of 100%[12] whereas an ADC threshold of $1.9 \times 10^{-3}\,mm^2/s$ yielded 96.9% sensitivity and 98.1% specificity in the colorectum, and 85.9% sensitivity and 81.6% specificity in the ileum.[13] Similarly, using CDAI as reference standard and a threshold ADC of $1.17 \times 10^{-3}\,mm^2/s$, we had 100% sensitivity and 88% specificity.

The DWI hyperintensity was visually greater than that of T2-weighted MRI in the same inflamed bowel wall relative to the adjacent normal bowel wall. As b value increased gradually, the signal intensities of inflamed bowel segments were gradually increased. The interobserver agreement for the scores of DWI signal intensity between 2 radiologists was satisfactory in our study. Diffusion-weighted MR imaging is suitable for the patients in whom oral preparation or intravenous contrast could not be administered.[1] In addition, its rapid acquisition in free-breathing mode with reduction of motion artifacts would be more tolerable in children and weak patients.[10] The intestinal lumen, however, remained hyperintense on high b value DWI because of high viscosity of the intraluminal content especially in the large intestine resulting in false positive diagnosis. Good bowel preparation or negative oral contrast agent with low T1 and T2 signal intensities may obviate this problem. Collapsed bowel segments also had high DWI signal intensities that were lower than that of renal cortex in our study. The intestinal lumen should be distended with sufficient amount of oral contrast agent. Because of the low spatial resolution of DWI, assessment of activity should be combined with high spatial resolution T2- or contrast-enhanced T1-weighted sequences. Image fusion of DWI with standard MRI sequences allowed simultaneous anatomic and functional evaluation of inflamed bowel segments.[10] The ADCs of bowel wall may be overestimated because of ROI overlapping the intestinal content especially in the normal bowel wall. To ensure accuracy of the ADC measurement, we placed 3 ROIs on the bowel wall without covering the intestinal content on magnified ADC maps.

Our study had some limitations. First, both small and large intestinal segments were included in the ADC analysis. The ADCs of large bowel have been reported to be lower in 1 study because of high viscosity of the bowel content[9] and similar to that of small bowel in another study.[10] We had been careful to avoid the bowel content in the ROI of bowel wall. Second, this study evaluated only 1 intestinal segment in each patient. Actually multiple lesions at different stages of inflammation are frequently observed in CD patients. The assessment only in 1 location with most marked abnormalities might not be sufficient for evaluating the global activity of CD, but we thought it could represent most accurately the CD activity and be applicable to analyze with CDAI. Third, although CDAI is produced more, based on the subjective criteria, it is easy and common to use in clinic. The correlation between the CD activity assessed by endoscopic result and DWI will be analyzed in our next research.

In conclusion, DWI is useful for detecting and localizing active CD. Both DWI and ADC correlated well with disease activity and had excellent accuracy for differentiating active from inactive CD.

REFERENCES

1. Makanyanga JC, Taylor SA. Current and future role of MR enterography in the management of Crohn disease. *AJR Am J Roentgenol.* 2013;201:56–64.
2. Gucer FI, Senturk S, Ozkanli S, et al. Evaluation of Crohn's disease activity by MR enterography: derivation and histopathological comparison of an MR-based activity index. *Eur J Radiol.* 2015;84:1829–1834.

3. Menys A, Atkinson D, Odille F, et al. Quantified terminal ileal motility during MR enterography as a potential biomarker of Crohn's disease activity: a preliminary study. *Eur Radiol.* 2012;22:2494–2501.
4. Ream JM, Dillman JR, Adler J, et al. MRI diffusion-weighted imaging (DWI) in pediatric small bowel Crohn disease: correlation with MRI findings of active bowel wall inflammation. *Pediatr Radiol.* 2013;43:1077–1085.
5. Oto A, Kayhan A, Williams JT, et al. Active Crohn's disease in the small bowel: evaluation by diffusion weighted imaging and quantitative dynamic contrast enhanced MR imaging. *J Magn Reson Imaging.* 2011;33:615–624.
6. Maccioni F, Patak MA, Signore A, et al. New frontiers of MRI in Crohn's disease: motility imaging, diffusion-weighted imaging, perfusion MRI, MR spectroscopy, molecular imaging, and hybrid imaging (PET/MRI). *Abdom Imaging.* 2012;37:974–982.
7. Shenoy-Bhangle AS, Nimkin K, Aranson T, et al. Value of diffusion-weighted imaging when added to magnetic resonance enterographic evaluation of Crohn disease in children. *Pediatr Radiol.* 2015 Aug . doi:10.1007/s00247-015-3438-1.
8. Oto A, Zhu F, Kulkarni K, et al. Evaluation of diffusion-weighted MR imaging for detection of bowel inflammation in patients with Crohn's disease. *Acad Radiol.* 2009;16:597–603.
9. Kiryu S, Dodanuki K, Takao H, et al. Free-breathing diffusion-weighted imaging for the assessment of inflammatory activity in Crohn's disease. *J Magn Reson Imaging.* 2009;29:880–886.
10. Neubauer H, Pabst T, Dick A, et al. Small-bowel MRI in children and young adults with Crohn disease: retrospective head-to-head comparison of contrast-enhanced and diffusion-weighted MRI. *Pediatr Radiol.* 2013;43:103–114.
11. Macarini L, Stoppino LP, Centola A, et al. Assessment of activity of Crohn's disease of the ileum and large bowel: proposal for a new multiparameter MR enterography score. *Radiol Med.* 2013;118:181–195.
12. Buisson A, Joubert A, Montoriol PF, et al. Diffusion-weighted magnetic resonance imaging for detecting and assessing ileal inflammation in Crohn's disease. *Aliment Pharmacol Ther.* 2013;37:537–545.
13. Hordonneau C, Buisson A, Scanzi J, et al. Diffusion-weighted magnetic resonance imaging in ileocolonic Crohn's disease: validation of quantitative index of activity. *Am J Gastroenterol.* 2014;109:89–98.