MRI Evaluation of Inflammatory Activity in Crohn’s Disease

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OBJECTIVE. We wanted to assess the capability of MRI to quantitatively evaluate the therapeutic response to Crohn’s disease (CD) relapse.

SUBJECTS AND METHODS. Twenty patients with histologically proven CD were prospectively evaluated with MRI and ileocolonoscopy over a 2-year period. The MRI protocol included axial and coronal T2-weighted and contrast-enhanced T1-weighted sequences. MRI examinations were performed twice, once during an acute relapse of CD and the other at clinical remission. The terminal ileum and colon were divided into six segments/patient, and the endoscopy and histology findings were considered the standard of reference. These were compared on a segmental basis with the quantitative MRI findings regarding wall thickness and contrast enhancement. The results obtained in active and remission CD phases were likewise compared with the findings in 10 controls who underwent complete ileocolonoscopy for other reasons and had no pathological findings on ileocolonoscopy.

RESULTS. Fifty-three of 120 (44.2%) bowel segments showed pathologic changes on endoscopy and histology consistent with CD in active phase. On changing from the active disease phase to clinical remission, a significant decrease was observed in the wall thickness and contrast enhancement of the affected bowel wall. In the active phase of CD, the pathologic bowel segments presented with significantly greater contrast enhancement and wall thickness values compared with the healthy segments of CD and controls. On converting clinically into remission, contrast enhancement tended to normalize, whereas bowel wall thickness remained increased compared with the controls.

CONCLUSION. MRI is able to detect pathologic bowel segments in CD, as it allows the measurement of significant variations in wall thickness and contrast enhancement on changing from the active phase of the disease to remission.

Crohn’s disease (CD) is an autoimmune disorder of an unknown cause that affects mainly young people after a chronic and relapsing course. No diagnostic technique is regarded as the gold standard for reliable and reproducible quantitation of CD’s inflammatory activity. Routine clinical management is based on the Crohn’s Disease Activity Index (CDAI) and especially on biologic parameters (acute phase reactants), with or without additional endoscopic and imaging procedures. In recent years, MRI has emerged as a diagnostic alternative applied to CD due to new pulse-sequence developments, along with the lack of ionizing radiation, which makes it more favorable to the usually young patient population. Different studies have confirmed the capability of MRI to detect pathologic bowel segments with high sensitivity and specificity [1, 2]. This technique plays an important role in diagnosing complications such as fistulas and abscesses [3, 4]. Nevertheless, few studies have investigated MRI’s capability to assess treatment response after a relapse of CD [5].

This study evaluates the capability of MRI to accurately assess inflammatory bowel changes when clinical remission occurs.

Subjects and Methods

Our institutional review board approved this prospective study, and informed consent was obtained from all individuals before the MRI examinations.

Study Subjects: Patients

Between August 1999 and September 2001, all patients with histologically proven and active CD [6] in whom an abdominal MRI was clinically in-
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Colonoscopy were performed by three experienced endoscopists in conscious and sedated patients (midazolam, 2–4 mgr IV). In every patient, the colon was divided into six segments: rectosigmoid, descending colon including the splenic angle, transverse colon, ascending colon and hepatic angle, cecum and ileocecal valve, and terminal ileum. From each bowel segment, a minimum of two biopsies were obtained, regardless of whether endoscopically manifest disease activity was detected. Pathologic segments were defined as those segments presenting any endoscopic lesion suggestive of CD (e.g., erythema/loss of vascular pattern, aphthoid ulcerations, polymorphic ulcerations, or a cobblestone appearance) and/or the existence of at least one of the following biopsy findings indicative of acute inflammatory activity: (a) presence of polymorphonuclear cells in the sample, (b) alterations in mucosal epithelial integrity, or (c) presence of granulomas or microgranulomas. Normal bowel segments were in turn

Subjects: Control Group

The control group consisted of 10 individuals (5 men and 5 women; mean age, 57.7 ± 13.29 years; range, 34–79 years old) who underwent colonoscopy for the following reasons: rectal bleeding/hemorrhoids in six cases, weight loss in two, and abdominal pain in two patients. In all cases, after complete exploration of the colon and terminal ileum, no evidence of organic lesions was found. In identical fashion as the patient group, these controls underwent an abdominal MRI within 24 hr after colonoscopy.

Colonoscopy

Colonoscopies were performed by three experienced endoscopists for CD. The inclusion criteria were (a) CDAI >150, (b) colonoscopic lesions suggestive of active CD (regardless of lesion grade), and (c) at least one elevated acute phase reactant (erythrocyte sedimentation rate [ESR] or C-reactive protein [CRP]). The exclusion criteria were (a) contraindications for MRI (electrically, magnetically, or mechanically activated devices; central nervous system hemostasia clips, or the inability to administer a gadolinium contrast agent because of known allergic problems), (b) pregnancy, and (c) HIV infection.

Sixty patients met the inclusion criteria and were initially included. All patients underwent complete colonoscopy with evaluation of the terminal ileum, and an MRI study within 24 hr (MRI in active disease). After therapy for active inflammatory disease, clinical remission (inactive disease) was considered in the presence of CDAI ≤150 and acute phase reactant (ESR and CRP) normalization. Of the 60 initial patients, a follow-up MRI study in the remission phase was possible in only 20 patients (11 men and 9 women; mean age, 33.5 ± 16.4 [SD] years; range, 17–73 years). There was a minimum of 30 days between both MRI studies (mean inter-exploration interval, 233.85 ± 154.92 days; range, 43–440 days).

Subjects: Control Group

The control group consisted of 10 individuals (5 men and 5 women; mean age, 57.7 ± 13.29 years; range, 34–79 years old) who underwent colonoscopy for the following reasons: rectal bleeding/hemorrhoids in six cases, weight loss in two, and abdominal pain in two patients. In all cases, after complete exploration of the colon and terminal ileum, no evidence of organic lesions was found. In identical fashion as the patient group, these controls underwent an abdominal MRI within 24 hr after colonoscopy.
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MRI Acquisition

MRI of the whole abdomen was performed using a 1.5-T MRI system (Signa LX-II, GE Healthcare) in 44 examinations (identified as scanner A); the Magnetom Sonata scanner (Siemens Medical Solutions) was used in 16 examinations (identified as scanner B). Gradient amplitudes of 23 and 40 mT/m, respectively, were used, with a phased-array multicoil for the body. Patients fasted for 7 hr before the MRI examination. Thirty min before imaging, patients were given 1,500 mL of a 2% diluted barium sulfate solution orally. Water (1,500–2,000 mL) was administered rectally for colonic distention just before imaging.

After acquiring standard three-plane scout images, the precontrast protocol included the following sequences: (1) axial T2-weighted (scanner A, single-shot fast spin-echo [SSFSE]; TR/TE, infinite/120); scanner B, half-fourier single-shot turbo spin-echo, HASTE; TR/TE, 1200/120, or true fast imaging with steady-state free precession [FISP]; TR/TE 4.3/2.1, 80° flip angle) from the xiphoid process to the pubis (around 40 sections); (2) coronal fat-suppressed T2-weighted (SSFSE/HASTE or fast imaging sequences; (1) axial T2-weighted (scanner A, FMPSPGR, TR 220, 90° flip angle, field of view, 46 cm; scanner B, turbo fast low-angle shot [turbo FLASH], TR 147, 70° flip angle, field of view, 40 cm); (4) coronal and axial fat-suppressed T1-weighted (scanner A, FMPSPGR, TR/TE 180/3, 90° flip angle, field of view, 40–48 cm; scanner B: turbo FLASH, TR/TE 105/1.9, 60° flip angle, field of view, 38 cm). In these sequences, the number of acquisitions was one, the section thickness was 6–7 mm with a 10–20% intersectional gap, and the imaging matrix was 256 × 151–168 (phase-frequency-encoding). A gadolinium chelate (gadopentetate dimeglumine, Magnevist, Schering) was injected in a dose of 0.1 mmol/kg of body weight as a bolus injection at 3 mL/sec using a power injector (Ulrich). This was followed by the acquisition of a coronal T1-weighted fat-suppressed 2D spoiled gradient-recalled echo sequence (machine A, FMPSPGR; machine B, 2D FLASH and 2D turbo FLASH and 3D volume interpolated breath-hold examination [VIBE]; TR/TE 4.2/1.8, 12° flip angle, field of view, 400 mm, 2–3 mm thickness; number of excitations, 1; matrix, 256 × 144). This sequence was acquired three consecutive times, the first time 20–30 sec after the start of contrast agent injection, and the following two times spaced 30 sec apart. A single late acquisition in the axial plane was obtained 4–5 min after contrast agent injection with the same sequence.

The locations of the different sequences and the number of planes were always the same in the axial and coronal T2-weighted acquisitions.

Pre- and postgadolinium wall signal intensity and wall-thickness measurements were obtained with slices corresponding to three different T1-weighted sequences: FMPSPGR, 13 examinations in CD patients and three in controls or FLASH (13 examinations in CD patients and 12 in controls); turbo FLASH Fat Sat (11 examinations in CD patients); and 3D VIBE (three examinations in CD patients and five in controls).

Image Analysis

Pre- and postcontrast T1-weighted images were quantitatively analyzed for colonic wall contrast enhancement (CE) and thickness with a dedicated postprocessing workstation (Advantage Windows v4.0, GEMS; Leonardo, Siemens). This image analysis was performed by the same board-certified radiologist experienced in the interpretation of MRI, who was blinded to the clinical score, symptoms, and colonoscopy findings. Images were also shown to the reviewer in a random order for analysis.

Quantitative measurement of CE was assessed as the percentage increase in wall signal intensity (WSI) on administering gadolinium contrast with respect to the baseline signal before contrast agent injection using the following formula [7, 8]: CE = (WSI post-gadopentetate dimeglumine – WSI pre-gadopentetate dimeglumine/WSI pre-gadopentetate dimeglumine × 100 × (SD noise pre- / SD noise post-), where WSI corresponds to the average of five WSI measurements, SD noise pre- is the SD of the signal intensity measured outside of the body in the region anterior to the abdomen (noise region of interest [ROI], 1 cm2) before gadopentetate dimeglumine injection, and SD noise post- corresponds to the SD of the same noise ROI after gadopentetate dimeglumine administration.

The ROI within the colon wall was placed at the same segment location, preferably in the areas with larger thickening, avoiding scantly distended or artificial segments both after contrast agent injection (WSI pre-gadopentetate dimeglumine) and after contrast administration (WSI post-gadopentetate dimeglumine) (Fig. 1). On average, the MRI analysis time per patient was 10–15 min. The ROI was placed in the wall of the affected segment on the precontrast image; after this, the ROI was copied and pasted in the postcontrast image.

Quantitative assessment of bowel thickening was measured in millimeters. Bowel wall thickening secondary to inflammatory edema and transmural fibrosis allowed differentiation between pathologic and normal bowel segments in patients with CD [5, 9]. Bowel wall thickness was measured manually at the active colon segments using the distance-measuring tool available on the workstation. This was done in well-distended, orthogonally imaged loops to both axial or coronal fat suppressed contrast-enhanced images (Fig. 1).

Statistical Analysis

All statistical analyses were performed using commercially available dedicated software (Microsoft Excel 2000). The Student’s t test for paired data was used to evaluate differences between CE and thickness of the active bowel segments in the different activity phases of CD, while the Student’s t test for independent variables was applied to compare these same values between the group of patients with CD and the control group. A statistically significant difference between the groups was considered to be p < 0.05.

Results

A total of 40 MRI studies were evaluated in the CD patient group (20 in the active phase and 20 in remission), and 10 healthy controls. No patient underwent bowel surgery before the MRI studies. The MRI examinations during CD’s active phase were performed in 13 inpatients and 7 outpatients. All 20 MRI examinations performed during the disease’s remission phase were as outpatients.

Table I: Comparison of MRI Findings in the Active Disease Bowel Segments According to the Crohn’s Activity Phase

<table>
<thead>
<tr>
<th></th>
<th>Active Phase (mean ± SD)</th>
<th>Remission (mean ± SD)</th>
<th>Difference ± SD</th>
<th>Paired Student’s t test</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE (@ 53 sec) (%)</td>
<td>142.5 ± 101.8</td>
<td>119.7 ± 104.9</td>
<td>22.8 ± 37.3</td>
<td>p &lt; 0.001 S</td>
</tr>
<tr>
<td>Thickness (@ 53 sec) (mm)</td>
<td>6.93 ± 3.02</td>
<td>4.91 ± 2.31</td>
<td>2.01 ± 2.58</td>
<td>p &lt; 0.001 S</td>
</tr>
</tbody>
</table>

Note.—CE = contrast enhancement; S = significant.
Regarding patient treatment in the active phases of CD, all subjects received combined therapy with two or more drugs (systemic corticoids in 55% of cases, topical corticoid [budesonide] in 10%, 5-aminosalicylic acid in 45%, and immune suppressors in 15%). During the remission periods, 16 patients received maintenance monotherapy in the form of 5-aminosalicylic acid, while four received combined aminosalicylates and immune suppressors. In the CD group, one abscess was diagnosed, along with one enterocutaneous fistula and two enteroenteric fistulas.

Colonoscopy

For comparison purposes, 53 segments were taken and regarded as pathologic; the remaining 67 were regarded as normal (healthy segments) in the 20 patients with CD, according to the gold-standard test. Sixty segments belonged to the 10 control patients. A total of 265 biopsies were taken from the 120 bowel segments initially examined in the CD group. There were coincidental results with visual assessment by endoscopy regarding disease activity in 83% (220/265) of the biopsies. In the remaining 17% (45/265) of biopsies, there was no correlation due to lack of endoscopical findings in the presence of histologic changes (granulomas in 20/265 biopsies, 7.6%) or lack of acute activity microscopic changes despite evident endoscopical changes (25/265 biopsies, 9.4%).

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**Fig. 2.**—Ileal thickening in 27-year-old patient with Crohn’s disease.

A. Barium study of small bowel shows involvement of long ileal segment (25 cm) from ileocecal valve.
B. Homogeneous ileal wall thickening (fast imaging with steady-state free precession) without extramural involvement (intact mesenteric fat).
C. Postcontrast fat-suppressed T1-weighted (2D fast low-angle shot) image obtained during the active phase (Crohn’s disease activity index [CDAI] = 275; erythrocyte sedimentation rate [ESR] = 75, C-reactive protein [CRP] = 12) shows thickening of terminal ileum (7.5 mm) and significant enhancement (contrast enhancement = 151%) of mucosa and serosa (arrows).
D. Amplified portion of C shows layered enhancement pattern.
E. Three months after recurrence and after medical treatment (CDAI <150, normal ESR and CRP), signal intensity and thickness of affected bowel wall have clearly decreased (arrows) (CE = 106% and 4.1 mm, respectively).
F. Amplified portion of E shows persistence of layer pattern after medical treatment.
Regarding the correlation between colonoscopy and MRI, 5.8% (7/120) of the segments had normal findings with endoscopy and histology, but an evident pathologic wall thickening (5.34 ± 2.71 mm; range, 3.1–7.5 mm) and contrast enhancement (133.41 ± 112.03%; range, 75.32–201.23%).

**Quantitative MRI Analysis**

**Contrast Enhancement.**—Within the CD patient group, a decrease in the mean values of CE occurred from the active to the remission phase, which showed a statistical significance compared on a segment-by-segment basis (paired Student’s t test) (Table 1), (Figs. 2–4). The mean CE of the active bowel segments in patients with CD was greater than in the control group (p < 0.05), although this difference disappeared upon reaching remission. Likewise, no statistical significant differences in mean CE were recorded between the healthy bowel segments in the CD group and the control series (Table 2).

**Bowel Wall Thickness.**—In the CD patient group, a statistically significant decrease in wall thickness occurred within the segments between active and remission status (Table 1). In addition, mean bowel wall thickness of the pathologic segments in the CD group was also significantly greater than in the control group, in both the active and remission phases. No differences in wall thickness were observed in the healthy bowel segments of the CD group versus the controls (Table 2).

**Discussion**

Several diagnostic techniques in the past few decades, particularly in the field of imaging technology, have improved the diagnosis of CD [7, 10], allowing us to evaluate its extent and diagnose its complications earlier [3, 4]. Scintigraphy with labeled leukocytes (HMPAO-Tc99) [11, 12] and abdominal sonogram [12, 13] are still far from providing acceptable sensitivity and specificity per bowel segment in detecting the disease’s inflammatory activity. Helical CT allows the distinction between the active and remission phases of CD [14]. However, the patient’s exposure to ionizing radiation limits its excessive use, according to patient age and the relapsing nature of the disease.

![MRI Evaluation of Inflammatory Activity in Crohn's Disease](image)
Fig. 4.—22-year-old woman with Crohn’s disease. Axial gadolinium-enhanced fast multplanar spoiled gradient-recalled echo image with fat suppression and oral and rectal water administration shows increased signal intensity and pathologic mural thickness (7.8 mm) in terminal ileum (arrow).

Thus, assessment of treatment response after recurrence continues to depend on clinical and laboratory testing, especially acute phase reactants [15]. Imaging techniques are reserved for evaluating the disease’s complications; MRI has been shown to be useful in CD [2, 3, 5, 9, 16–19]. Some authors have reported a great sensitivity and specificity per bowel segment in detecting inflammatory activity and differentiating it from the inactive segments [2]. Other investigators have in turn observed a good correlation between MRI and endoscopy [1, 10] or between MRI and clinical settings [2] in patients with CD. Madsen et al. [5] reported variations in CE after medical treatment, although their study was limited by the few patients enrolled. Other authors have reported similar results with other techniques, such as computed axial tomography [15]. Our results were similar to these previous studies, as we also measured a significant decrease in CE on evolving from the active to the remission phase of CD.

For CE measurements, we applied a formula similar to that used by Semelka et al. [8], since it is simple and reproducible, and the results (expressed as a percentage) allowed us to include all the MRI examinations regardless of the pulse-sequence type used.

Despite CE decrease in the pathologic segments from active to remission phase, these segments remained pathologically thickened in both phases compared with the control group. This may be explained by the fact that thickening possesses an acute and therefore reversible component (inflammation and edema), and a chronic component (fibrosis) that does not reverse despite treatment response.

We decided to exclude patients with HIV infection, since CD is very rare in immunosuppressed patients. In addition, colitis and ileitis of infectious origin, such as tuberculosis, Mycobacterium avium, or cytomegalovirus cause lesions endoscopically similar to those of CD.

Our study was limited by the reduced number of bowel segments compared in CD patients and controls. This was due to the need to include only the pathologic segments (a mere 53 of the 120 total segments) and the high cost of MRI compared with other imaging techniques, such as sonogram or barium contrast enema. We tried to obtain a control group of similar age to the patient group, but the corresponding young age population is less inclined to undergo a colonoscopy; thus, colonoscopy is usually performed in an older population.

We established an interval between both MRI studies of over 1 month (mean, 233 days), since a shorter interval would possibly only reflect clinical changes, with little variation in inflammation at a local level. We also did not consider it advisable to repeat colonoscopy in the remission phase, since it has been shown to be of little benefit in the follow-up of CD patients [20]. To have a well-distended colon and terminal ileum, both barium sulfate orally and water as an enema were given to the patient simultaneously. Since both act as negative contrast agents on T1-weighted sequences, postgadolinium measurements of the bowel wall can be done better.

Another limitation of our study was the manual placement of the ROI over the bowel wall, as this implies bias, because the cursor may not be placed precisely on target. We calculated the mean of five measurements to overcome this problem. Nevertheless, it must be considered that all measurements were made by the same radiologist, who has extensive experience in the field, instead of by two or more reviewers as usual. We decided to sustain the study on numeric values lacking subjectivity, taken from each of the 120 segments of the CD patients, with total blinding to the colonoscopy and histology findings. Our routine imaging protocol for CD patients comprises T1- and T2-weighted sequences, although the measurements of the present study are limited to the former. Due to practical daily working needs and the fact that we use MRI systems from two different vendors, we adapted the protocol over time with various T1-weighted sequences. Initially we used FMPSGR and FLASH sequences; later, we incorporated the fat-suppressed 2D turbo FLASH and 3D VIBE sequences, which, in our opinion, improved image quality compared with the former sequences. In our institution, we use abdominal MRI in CD patients mainly for assessing internal and external abdominal fistulas, other small bowel disorders than those affecting the terminal ileum, and for completing the study of colon stenoses and their degree of activity. In addition, we use MRI to avoid ionizing radiation exposure in the pediatric CD population and in women during pregnancy. We continue to use CT to evaluate intraabdominal

### TABLE 2 Comparison of MRI Results in Crohn’s Disease Group Versus Control Group

<table>
<thead>
<tr>
<th></th>
<th>Controls Pathological Segments</th>
<th>Crohn’s Disease Pathological Segments</th>
<th>Healthy Segments</th>
<th>p&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>Active Phase</td>
<td>Thk (mm) 3.87 ± 0.88 (60 segments)</td>
<td>6.93 ± 3.02 (53 segments)</td>
<td>3.11 ± 1.46 (67 segments)</td>
<td>p = 0.23 NS</td>
</tr>
<tr>
<td>Remission</td>
<td>CE (%) 108.2 ± 53.5 (60 segments)</td>
<td>142.5 ± 101.8 (53 segments)</td>
<td>112.3 ± 14.6 (57 segments)</td>
<td>p = 0.44 NS</td>
</tr>
<tr>
<td></td>
<td>p&lt;sup&gt;a&lt;/sup&gt;</td>
<td>p&lt;sup&gt;b&lt;/sup&gt;</td>
<td>p&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
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<tr>
<td></td>
<td>Thk (mm) 3.37 ± 0.88 (60 segments)</td>
<td>6.93 ± 3.02 (53 segments)</td>
<td>3.11 ± 1.46 (67 segments)</td>
<td>p = 0.23 NS</td>
</tr>
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</tr>
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Note.—CE = contrast enhancement; S = significant; NS = nonsignificant; Thk = bowel loop wall thickness.

<sup>a</sup>Student’s t test control group-active phase.

<sup>b</sup>Student’s t test control group-remission phase.

<sup>c</sup>Student’s t test control group-CD healthy segments.
fluid accumulations (phlegmons and abscesses) or mesenteric fat disorders.

Our results show that MRI clearly allows the distinction of pathology from normal bowel wall in CD, as it detects significant variations in bowel wall thickness with clinical improvement and is able to reflect pathologic inflammatory changes at the bowel wall based on variations in the CE. Consequently, this technique is reliably applicable to the follow-up of patients with CD. More extensive series should be investigated that involve defined disease patterns (fibrosing, inflammatory, fistulizing) to more precisely define the role of MRI in patients with Crohn’s disease.

MRI is able to detect significant variations in bowel wall thickness and contrast enhancement, reflecting favorable clinical response to medical treatment of CD’s relapse. In addition to its lack of ionizing radiation, this may allow MRI to be the imaging technique of choice for the follow-up of patients with active CD.

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