Crohn's disease, advances in MRI
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Citation for published version (APA):

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Figures

Figures belonging to chapter 2 through 8
Figure 1. Transverse SSFSE image shows large B1-inhomogeneity artifact (drop in signal intensity; arrows).

Figure 2. B-SSFP scan of a patient (left) and a combined image (right) with different phase cycling, i.e. in each acquisition the location of the banding pattern changes. Patient preparation consisted of fasting for 4 hours before the scan followed by drinking 1600 ml mannitol 2.5% in 1 hour before the scan. Scan parameters were: TR/TE=5.4/1.8 ms, FA=40º; 20 sagittal slices; FOV=350×350 mm; voxel size=2.0×2.0×2.0 mm. Courtesy Sonia I. Gonçalves, AMC, Amsterdam, The Netherlands.

Figure 3a: Dark lumen MR colonography in a 64-year-old patient. Rectal CO2 insufflation was used to distend the colon and faecal tagging with an iodinated contrast agent was used to homogeneously label the stool. The coronal 3D T1-weighted gradient echo sequence shows a dark colonic lumen.

3b. Bright lumen MR colonography in a 62-year-old male patient. The colon was distended by an oral contrast agent that contained 10 mL gadolinium (0.5 mmol/mL) and rectal administration with a mixture of water and gadolinium-based contrast agent (10mmol/L). The coronal 3D T1-weighted fast field echo sequence demonstrates high signal intensity of the colonic lumen.

Figure 4. Bright lumen MR colonography with supine (A) and prone (B) positioning. The transverse 3D T1-weighted fast field echo demonstrates that the stool is affected by gravity as the patient changes position; supine and prone.
Figure 5. Dark lumen MR colonography in a 60-year-old male patient.

5 a. Coronal 3D T1-weighted gradient echo image in supine position. The transverse colon is well distended.

5 b. This is contrary to the coronal 3D T1 weighted image in prone position where the colon is not well distended.

Figure 6. Dark lumen MR colonography in 79-year-old female patient with symptoms of abdominal pain and weight loss. CO2 insufflation was used for colonic distension and an iodinated oral contrast agent was used for faecal tagging.

6 a. Coronal 3D T1-weighted gradient echo sequence with fat saturation after intravenously administered paramagnetic contrast agent demonstrates a polyp in the sigmoid (arrow).

6 b. The presence of a hyperplastic polyp of 12mm was confirmed at conventional colonoscopy and pathology.

7a and 7b. Coronal T1-weighted image with fat saturation demonstrates two sessile polyps in the sigmoid close to each other.

7 c. Both polyps were confirmed at conventional colonoscopy, the size was 4 and 5mm, respectively. Histopathology demonstrated one hyperplastic polyp and one adenoma with low-grade dysplasia.
Figure 8. 3T scan versus 1.5T scan of female Crohn’s disease patient.

8 a. Coronal 3T T2-weighted SSFSE image shows thickened terminal ileum (arrows), with a large ulceration (curved arrow).

8 b. Coronal 3T T1-weighted gradient echo image with fat suppression after intravenous contrast shows stratified enhancement: enhancing serosa and (sub)mucosa (arrows) of the ileal loop, indicating inflammation.

Follow-up 1.5T scan of the same patient after 8 months of Infliximab therapy.

8 c. Coronal b-SSFP image with fat saturation at 1.5T shows thickened bowel wall (arrow) and the presence of the comb sign (open arrow).

8 d. Coronal T1-weighted gradient echo image with fat saturation at 1.5T shows homogeneous enhancing bowel wall (arrow).

Figure 9. 47-year-old female patient with Crohn’s disease.

9 a. Coronal SSFSE image at 3T shows thickened terminal ileum. The wall is two-layered (arrow), a hypointense mucosa, submucosa and a hyperintense muscularis, which is caused either by edema or intramural fat.

9 b. Coronal T1-weighted gradient echo image with fat saturation after intravenous contrast shows a layered appearance of the bowel wall (arrow) with enhancement of (sub)mucosa and serosa, which indicates inflammation.

Figure 10. Female 27-year-old patient with Crohn’s disease. Transverse SSFSE image with fat saturation shows a thickened terminal ileum with an ulceration (arrow).
Figure 11. Coronal T1-weighted gradient echo image at 3T with fat saturation shows two enlarged lymph nodes (arrows). Also a thickened pre-terminal ileum loop is visible (open arrow).

Figure 12. Patient with Crohn’s disease. Coronal T1-weighted gradient echo image after intravenous contrast with fat saturation shows a fistula between two ileal loops (arrow).

Figures chapter 3

Figure 1: Importance of MRI features. Range: 1 not important, 10 very important. Medians with Inter Quartile ranges are given.
Figure 2: Percentage of respondents with thought the MRI feature was mandatory. Features are presented in order of most often used to least often used (highest above).

Figure 3: Implications for disease activity per MRI feature. Y-axis: Percentage of respondents that indicated the type of disease activity. The MRI features are displayed in order of the most often used for grading (highest above).

Figure 1: Distribution of AIS.

Figure 2: Forty-seven-year-old female patient with Crohn’s disease.
2 A. Coronal true-FISP image shows thickened ileal wall (arrow).
2 B. Coronal VIBE image after intravenous contrast shows homogeneous enhancement (type D) of the ileal wall.
2. C. Histologic section through the ileum. Microscopic view shows mucosal ulceration (arrows), inflammation AIS: 11. (Hematoxylin-eosin stain; original magnification, 20x.)

Figure 3: Twenty-seven-year-old female patient with Crohn’s disease.

3. A. Transverse true-FISP image shows thickening of the ileal wall (arrow).

3. B. Transverse VIBE image shows enhancement of the mucosa (type B) of the ileal wall (arrow).

3. C. Macroscopic picture of the right-sid ed hemicolecction resection of this patient. There is an ileal stenosis (open arrows), the wall is thickened. The ileum is surrounded by fat, which has crept up around the ileal wall.

3. D. Transverse ultra fast gradient echo image of the same patient shows 3-layered (type A) enhancement of the cecum (arrow).

3. E. Histologic section through the colon. Microscopic view shows large mucosal ulceration (arrows) and a lymphoid aggregate (clustering of lymphocytes) (open arrow). AIS: 9. (Hematoxylin-eosin stain; original magnification, 20x.)
Figure 4: correlation disease chronicity and enhancement ratio.

Figures chapter 5

Figure 1. Female patient with Crohn's disease. Superficial ulcerations (mild ulcerative disease) in the terminal ileum at ileocolonoscopy.

1 A. Post contrast 3D T1-weighted spoiled gradient echo image shows inflamed terminal ileum with homogeneous hyperenhancement and thickened bowel wall.

1 B. ROIs of bowel segments drawn on DCE MRI sequence (red = terminal ileum, green = cecum and ascending colon, blue = transverse colon, yellow = descending and sigmoid colon).

1 C. Maximum enhancement map shows high enhancement (red colour) of terminal ileum.

1 D. Shape map shows a relative high number of type 3 pixels in inflamed terminal ileum.
1 E. Example of mean TIC of the terminal ileum in this patient used for determining maximum enhancement and initial slope of increase. Maximum enhancement = maximum signal difference/signal baseline.

Figure 2. Classification of TICs. Type 1 (gray): no enhancement; Type 2 (green): slow enhancement, maximum of the curve is reached after half scan; Type 3 (blue): quick enhancement, followed by a signal plateau; Type 4 (magenta): fast enhancement and quick washout; Type 5 (yellow): quick enhancement, followed by a slow constant enhancement; Type 6 (red): artery; Type 7 (white/light gray): all others.

Figure 3. Scatterplots.

3 A. Scatterplot of wall thickness and CDEIS per segment shows correlation of $r=0.418$ ($p<0.001$). Data is somewhat skewed due to many segments with no disease activity.

3 B. Scatterplot of maximum enhancement and CDEIS per segment shows a correlation of $r=0.485$ ($p<0.001$).
Figure 4. Box plots of (DCE-)MRI values (median with IQR) for the four disease severity groups.

4 A. Enhancement ratio. No significant differences in enhancement ratios.

4 B. Mural signal intensity SS-FSE ratio. No significant differences between groups.

4 C. Maximum enhancement (ME). There was a significant difference in maximum enhancement between the normal mucosa and superficial ulcerations group and the normal mucosa and deep ulcerations group.

4 D. Initial slope of increase (ISI). There was no significant difference between the groups, although a trend was observed that initial slope of increase increased with disease severity.

4 E. Wall thickness. There was a significant difference between the mild ulcerative disease group and normal mucosa group.
Figure 5. Female 28 year old patient who previously underwent a ileoocoecal resection. Colonoscopy showed superficial ulcerations of the neoterminal ileum.

5 A. Coronal SSFSE images shows a wall thickness of 3mm in the neoterminal ileum (arrow).

5 B. Axial post contrast 3D SGE image shows mild enhancement of the neoterminal ileum (arrow).

Figure 6. Female patient with severe ulcerations in the transverse and ascending colon at colonoscopy.

6 A. Axial SSFSE image shows a wall thickness of 3mm in the transverse colon (arrow head).

6 B. Axial post contrast 3D SGE image shows moderate enhancement of the transverse and ascending colon (arrow heads).
Figure 7. Illustration of the gating and registration procedure. A. One time slice of a single subject. This slice, averaged over time before (B) and after (C) gating and registration, with a space-time plot along the brown (B-t) and yellow (C-t) bars.

7 D. The Sum of Squared Differences (SSD) with respect to the center volume, with an inset, showing that volumes in expiration were automatically selected. The breathing pattern can be identified by the oscillating pattern in Figure 7:B-t. The time averaged slice after registration shows a clear improvement in contrast. On average, one out of five volumes was selected, resulting in an effective time resolution of 4 seconds.

Figure 1. ROC graph depicting the sensitivity and specificity of the different (combinations of) modalities.
Figure 2. 16 year old male patient with Crohn’s disease. At colonoscopy swelling, deep ulceration were seen in the terminal ileum and cecum. MR entero- and colonography and ultrasound both diagnosed Crohn’s disease.

2 A+B. axial and coronal T2w SSFSE image with fat saturation shows thickened bowel wall (6 mm both observers, arrow) with high signal intensity of the terminal ileum indicating edema in the wall.

2 C. Axial T1 weighted SPE image shows layered enhancement (arrow).

2 D. Ultrasound shows thickened terminal ileum of 3.4 cm.

2 E. Endoscopy shows deep ulcerations in the cecum.

Figure 3. 16 year old female patient with ulcerative colitis. Mild lesions in ascending colon, transverse colon, descending colon and rectum. Severe lesions in ascending colon. Based on MR entero- and colonography both observers diagnosed as no IBD, but IBD was diagnosed with ultrasound.

3 A. Endoscopy shows ulcerations in the ascending colon.
3 B. Coronal T2 weighted images shows no apparent thickened bowel wall (<3mm).

3 C. Contrast enhanced T1-weighted sequence shows no enhancement of the bowel wall.

3 D. Ultrasound of cecum shows normal bowel wall (2mm). On ultrasound diagnosis of Crohn’s disease was made due to dilatation of a small bowel loop (without a visible stenosis).

Figure 4. ROC graph depicting the sensitivity and specificity of the different modalities for diagnosing Crohn’s disease.

Figure 5. ROC graph depicting the sensitivity and specificity of the different modalities for diagnosing ulcerative colitis.
Figure 1: Diagram of perianal fistulas. SS = Suprasphincteric fistula; SF = Superficial fistula (or submucosal fistula); IS = Intersphincteric fistula; TS = Transsphincteric fistula; ES = Extrasphincteric fistula.

Figure 2. Anal ultrasound in a 35 year old male with Crohn’s disease.

2 A. The probe (P) is in the rectum. A large hypoechogenic (H) area is visible at and just above the level of the puborectal muscle.

2 B. Hydrogen peroxide is injected in the external fistula opening. The tract to the internal opening (i.o.) is visible. The fistula (f) branches are visible at the level of the external anal sphincter.

2 C. The hypoechogenic area is now partly hyperechogenic and a horseshoe configuration of the fistula becomes clear.

2 D. Longitudinal image. The extend of the fistula is clearly visible.

Figure 3. 40 year old man with Crohn’s disease and a perianal fistula.

3 A. Coronal T2-weighted fast spin-echo image shows a transsphincteric fistula (curved arrows) at the right side with a seton in situ (arrow). The rectal wall is thickened, some small lymph nodes and some adjacent fat infiltration indicating disease activity at the rectum. L = levator ani muscle, E = external sphincter muscle.
3 B. Diagram of the image 3a, the fistula is indicated in yellow.

3 C. Axial T2-weighted fast spin-echo image shows the transsphincteric course of the track and the internal opening with seton (S). The track is wide and hyperintense (curved arrow), indicating either granulation tissue or fluid. G = gluteal muscle.

3 D. Axial T1-weighted fat-saturated fast spin-echo image after intravenous contrast agent shows enhancement of almost the complete track, indicating that it is granulation tissue (curved arrow). L = levator ani muscle, E = external anal sphincter, IO = internal obturator muscle, G = gluteus muscle.

3 E. Diagram of image 3c and d, the fistula and granulation tissue are indicated in yellow.

Figure 4. 46 year old man with extensive Crohn’s disease who underwent proctocolectomy with ileostomy. G = gluteus muscle, P = prostate.

4 A. Axial T2-weighted fast spin-echo image shows a hyperintense collection with extensive surrounding hypointense scar tissue.

4 B. At axial fat-saturated T2-weighted fast spin-echo image the collection is also hyperintense (arrow) indicating this could either be filled with fluid (i.e. abscess) or granulation tissue.
4 C. Axial fat-saturated T1-weighted fast spin-echo image obtained after administration of IV contrast medium shows strong enhancement of the rim whereas the core does not enhance, indicating an abscess with a rim of inflammatory tissue (arrow).

4 D. Diagram of image 4a, b and c. The abscess is indicated in yellow.

Figure 5. 42 year old man with a cryptoglandular fistula.

5 A. Coronal T2-weighted fast spin-echo image with endoanal coil shows a subtle transsphincteric fistula (curved arrow). I = internal anal sphincter, E = external anal sphincter, P = puborectal muscle, C = coil.

5 B. Diagram of image 5a. The fistula is indicated in yellow.

6 A. Coronal T2-weighted fast spin-echo image shows a transsphincteric fistula (curved arrow) with the internal opening (arrow). R = rectum, E = external sphincter, P = puborectal muscle

6 B. Diagram of image 6a. The fistula is indicated in yellow.

6 C. Axial T2-weighted fast spin-echo image shows a subtle internal opening (arrow) of the transsphincteric track (curved arrow).

6 D. Diagram of image 6c. The fistula is indicated in yellow.

Figure 6. 33 year old man with Crohn’s disease and a perianal fistula.
Figures chapter 8

Fig. 1 - Dynamic contrast-enhanced MR imaging findings in a 24-year old female with Crohn’s disease and a transsphincteric fistula. Seton in situ.

1 A. Axial oblique fat-saturated T2-weighted fast spin-echo image shows perianal fistulizing disease.

1 B. Maximum enhancement-map of the same section. Maximum enhancement of the perianal fistula is higher than that of the surrounding tissue.

1 C. TIC shape type map with in the fistula type 3 and 5 (fast rising pixels).

1 D. T2 weighted image of the same section.

Fig. 2 - Dynamic contrast-enhanced MR imaging findings in a 63-year old male with a transsphincteric fistula.

2 A. Axial oblique fat-saturated T2-weighted fast spin-echo image shows perianal fistulizing disease.

2 B. Maximum enhancement-map of the same section. Maximum enhancement of the perianal fistula is higher than that of the surrounding tissue.
Fig. 3 - $K_{\text{trans}}$ values before and six weeks after start of anti-TNF\(\alpha\) therapy. All $K_{\text{trans}}$ values decrease after anti-TNF\(\alpha\) therapy.

2 C. TIC shape type map.

2 D. T2 weighted image of the same section.