

Spectral Adiabatic Inversion Recovery (SPAIR) MR imaging of the Abdomen

Thomas C. Lauenstein

Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Germany

Background

Magnetic resonance imaging (MRI) has become a major imaging tool for the depiction and characterization of abdominal disease. Standard abdominal MRI protocols encompass different forms of T1-weighted (T1w) and T2-weighted (T2w) data acquisition. These sequences can be collected in less than 20 seconds, which typically is within the patients' ability to suspend respiration. Hence, artifacts due to physiological motion including respiration and bowel motion can be reduced, if not avoided. While most T1-weighted imaging techniques of the abdomen include gradient echo (GRE) sequences, T2-weighted imaging is based on the collection of single shot fast spin echo (SSFSE) data. The latter sequences in conjunction with fat saturation play a key role for the interpretation of different abdominal processes as liver lesions can be most accurately delineated and specified [1]. Furthermore, T2-weighted imaging with fat saturation is crucial for the depiction of edema and/or free fluid. This is particularly helpful for the depiction of inflammatory processes of the bowel, e.g. in patients with Crohn's disease [2, 3], appendicitis [4, 5] or diverticulitis [6–8]. Finally, T2-weighted data may be particularly useful in the setting of pregnant patients*. As the intravenous administration of gadolinium based contrast agents is contraindicated in this patient group, T1-weighted imaging is restricted and only provides limited information. Hence, T2-weighted imaging with fat saturation has been found to be the key sequence in pregnant* women with suspected abdominal inflammation or tumor disease [9–12]. Different techniques for fat saturation in MRI can be used. The most common

form in abdominal imaging is the use of a 180° excitation pre-pulse, which suppresses the signal specific tissue depending on the inversion time applied. The inversion time (TI) is set according to the T1 of fat in order to selectively null the fat signal (TI = 150-170 ms). In the most common implementation, the inversion pulse is applied with a wide frequency bandwidth to include both fat and water spins. A potential drawback to this approach is that the water signal will not be fully recovered during data acquisition, and the overall water signal-to-noise ratio (SNR) will be diminished. This can negatively impact the contrast-to-noise ratio (CNR) of lesions surrounded by tissue, such as tumors within the liver.

Technical considerations for SPAIR

The inversion recovery (IR) technique can be modified by using chemical selective or spectral pre-saturation attenuated inversion-recovery pre-pulses. SPAIR (Spectral Adiabatic Inversion Recovery) is a powerful technique for fat suppression which offers different advantages over conventional fat suppression techniques. The technique is insensitive to B1 inhomogeneities and only fat spins are suppressed/inverted. SPAIR uses a spectrally selective adiabatic inversion pulse to invert the fat spins in the imaging volume. After the adiabatic pulse a large spoiler is utilized in order to destroy any transverse magnetization. The fat spins will now decay according to the T1 relaxation rate and after a certain characteristic time (TI null) the longitudinal magnetization will be zero. At this time point the excitation pulse of the SSFSE T2-weighted module is applied. As the

fat spins have zero longitudinal magnetization at this point they will not contribute to the MR signal.

Clinical applications

Homogeneity and degree of fat suppression

The implementation of SPAIR fat suppression techniques will result in a more profound and homogenous fat saturation compared to conventional fat suppression techniques. In a recent study, SNR of mesenteric and retroperitoneal fat was measured for both IR and SPAIR fat suppression in conjunction with T2-weighted SSFSE imaging in order to determine the degree of fat suppression [13]. The study showed that improved fat suppression was found when SPAIR-SSFSE was applied (Fig. 1).

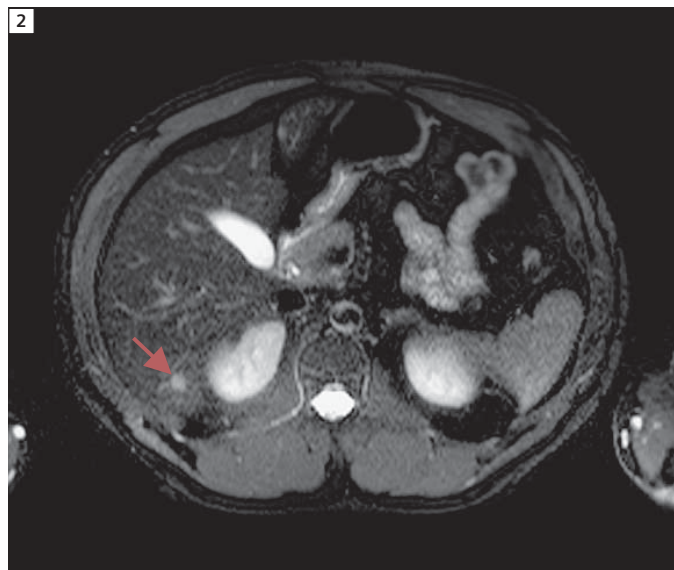
Depiction of anatomical structures

An advantage of SPAIR compared to conventional IR techniques is demonstrated by the improvement in CNR of the hepatic lesions. The better liver lesion contrast on SPAIR-SSFSE images is consistent with the predicted benefits of applying a frequency-sensitive inversion pulse. This leaves the maximum possible water signal intact as only the fat spins are inverted. Two types of focal liver lesions have been evaluated [13]: hemangiomas with a relatively high CNR and metastases with a relatively low CNR. The CNR was found significantly increased for both families of lesions when using SPAIR compared to IR SSFSE (Figs. 2 and 3).

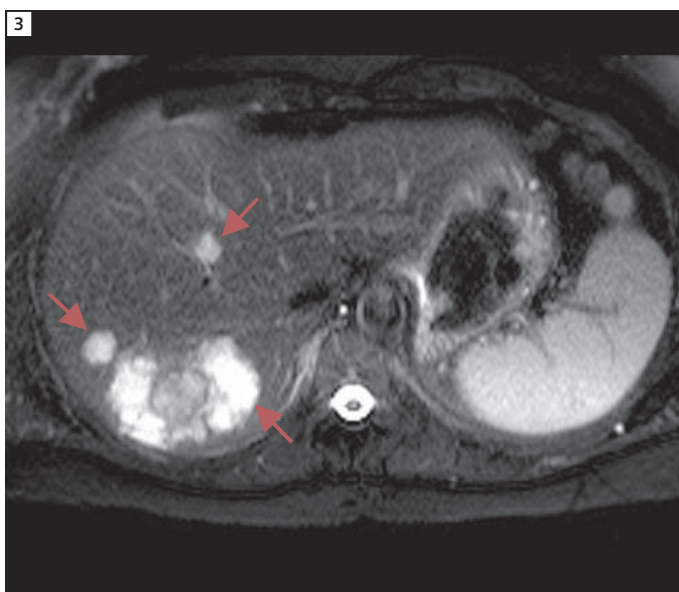
Furthermore, delineation of bowel wall structures is markedly improved on SPAIR SSFSE (Fig. 4). This improvement is due to two different factors that dif-



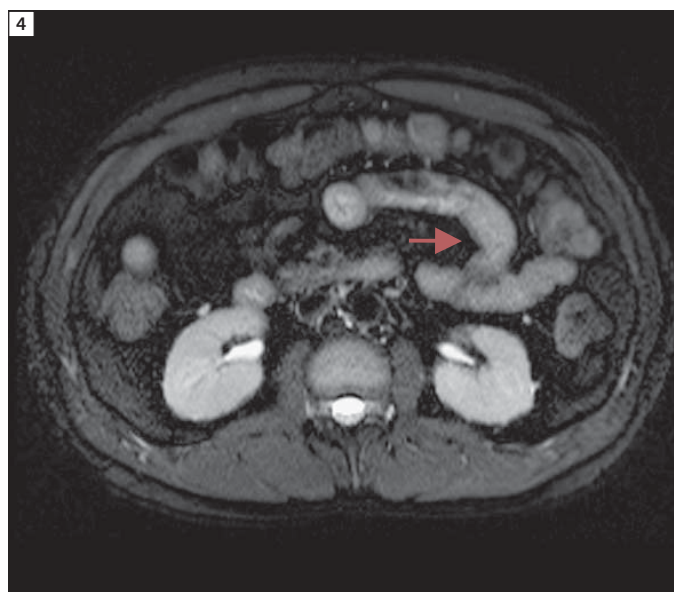
1 Homogeneous fat saturation in the retroperitoneum (dashed arrow) and the mesenteries (arrow) with the SPAIR technique.



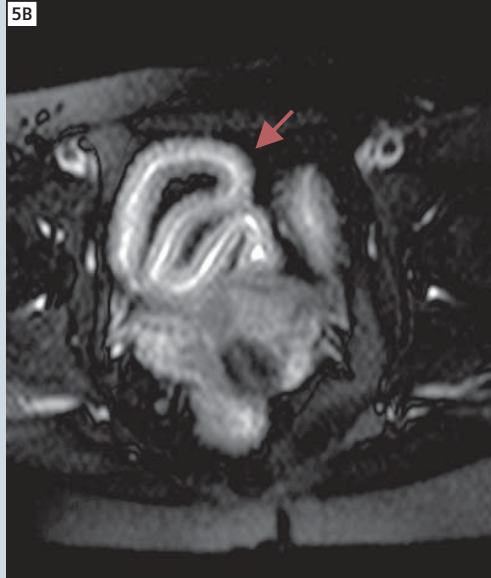
2 Patient with liver metastases (arrow) of colorectal cancer. The lesion is evident and provides high CNR values on SPAIR T2-weighted imaging.



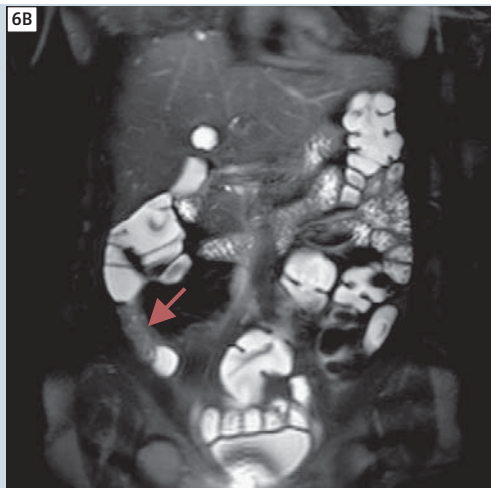
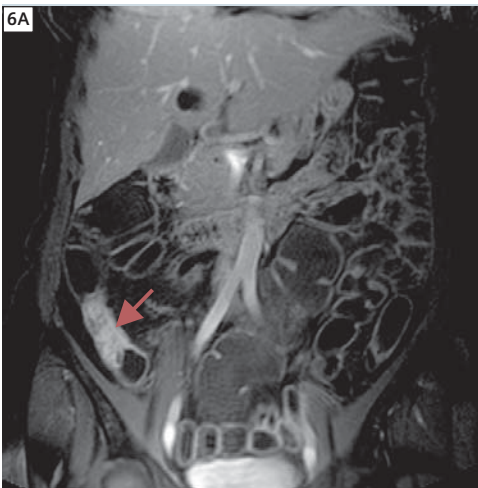
3 Patient with several hemangiomas (arrows). SPAIR T2-weighted MRI.



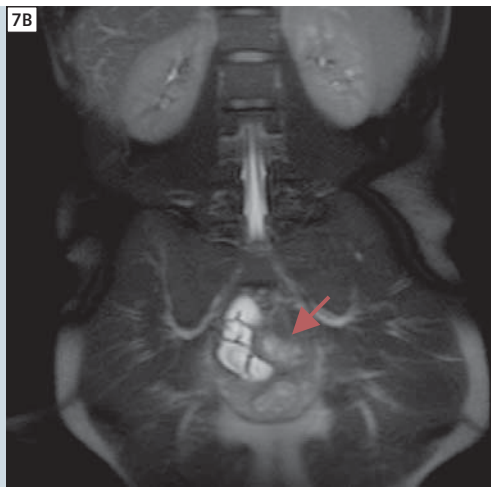
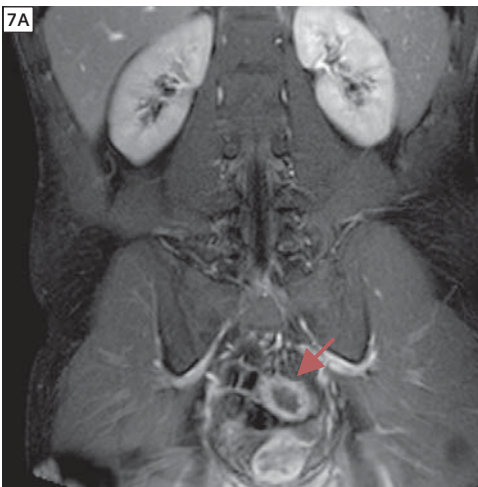
4 Conspicuous bowel loops (arrow) using the SPAIR technique.



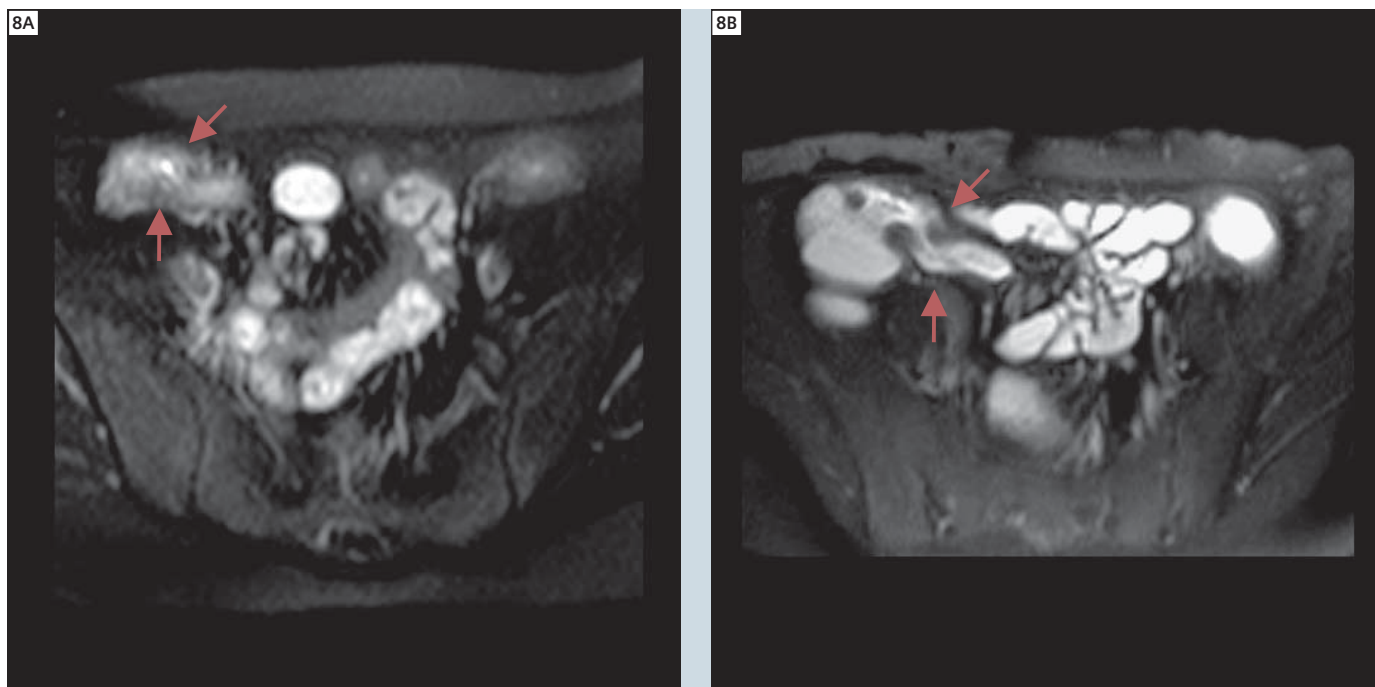
5 Patient with active colitis. There is increased contrast enhancement after iv gadolinium administration shown on T1-weighted GRE imaging (5A; arrow). A high T2 signal of the bowel wall can be depicted on T2-weighted SPAIR images (5B; arrow), which is consistent with active inflammatory disease due to edematous changes.



6 Patient with mildly active inflammatory changes of the ascending colon (arrow). T1-weighted contrast-enhanced MRI reveals increased contrast uptake of the inflamed bowel segment and thickening of the bowel wall (6A). The T2 signal on the SPAIR image is only slightly elevated (6B).



7 Patient with non-active / fibrotic inflammation of the sigmoid colon (arrow). Similar to the active forms of inflammatory bowel disease (IBD) there is increased contrast enhancement on T1-weighted MRI (7A). However, there is lack of edema, and thus the T2 signal is not elevated on the SPAIR image (7B).



8 SPAIR T2-weighted SSFSE MRI can be used as a stand-alone sequence for therapeutic monitoring. This patient presented with sign of active inflammation in the terminal ileum and highly elevated T2 signal on SPAIR imaging (8A). One week after the initiation of anti-inflammatory medication the T2 signal dropped as a correlation of therapeutic response (8B).

ferentiate SPAIR SSFSE: one factor is the relatively greater sensitivity to motion of standard IR SSFSE. In addition, bowel wall visualization should benefit from the increased SNR of water-containing structures on SPAIR SSFSE.

Inflammatory abdominal processes

Evaluation of disease activity in patients with inflammatory bowel disease (IBD) is often a challenging clinical situation. While active inflammation is treated with systemic corticosteroids or other immuno-modulator drugs, surgical therapeutic options are chosen for chronic disease. This discrepancy in therapy strategies underlines the need for an accurate categorization and differentiation between active and chronic disease. Attempts of classifying IBD in the past were based on different variables that

were either time-consuming (e.g. MR based perfusion analyses), invasive (colonoscopy / biopsy) or inaccurate (CDAI). Hence, a relatively fast, simple and non-invasive technique is desired in appraising the level of inflammatory activity and also in following up these patients for treatment response. SPAIR T2-weighted SSFSE sequences and gadolinium enhanced T1-weighted sequences are complementary techniques in patients with IBD [14]. Gadolinium-enhanced T1-weighted data is helpful to detect IBD independent of its activity state with a high sensitivity. However, accuracy of T1-weighted imaging to differentiate between active and non-active disease is only moderate. Enhancement patterns of T1-weighted imaging are unspecific: both bowel segments with active and chronic in-

flammation show an increased contrast enhancement [15]. Hyperintensity on T2-weighted images, however, is related to increased edema and inflammatory fluid components within or adjacent to the bowel wall, whereas T1-weighted hyperintensity may be attributed to a hypervascularity (in active disease) or a delayed wash-out (in fibrotic /chronic disease).

Examples of contrast-enhanced T1-weighted GRE images and SPAIR T2-weighted SSFSE images are shown in figures 5–7 for highly active, intermediate active and non-active IBD. Once the diagnosis of IBD is established, SPAIR T2-weighted SSFSE imaging can be used as a stand-alone sequence for therapy monitoring (Fig. 8). Furthermore, this method is also very helpful not only for the assessment of IBD including Crohn's

* The safety of imaging fetuses/infants has not been established.

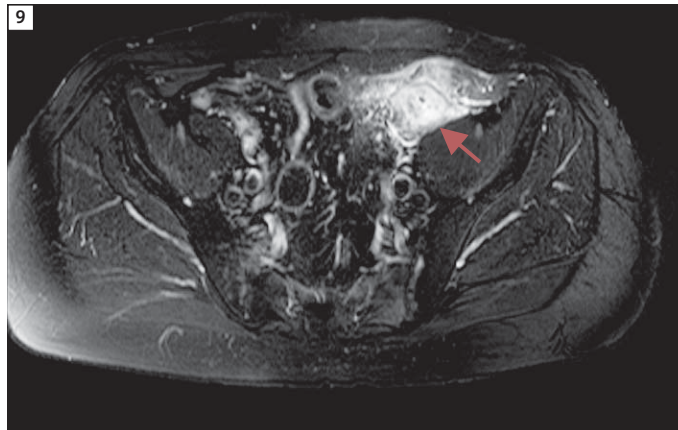
disease and Ulcerative colitis, but also for diverticulitis (Fig. 9) and the depiction of fistulae (Fig. 10).

Conclusion

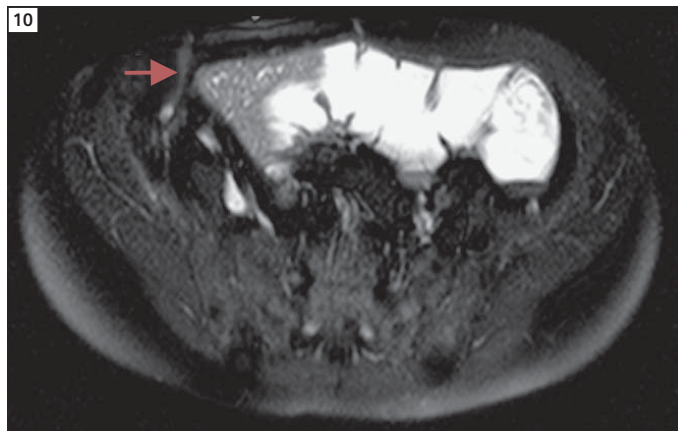
There are overall benefits of SPAIR SSFSE that can be measured on clinical abdominal MR images regarding fat saturation, particularly in fat adjacent to bowel and for improving overall image contrast even between non-fatty soft tissues, such as can be demonstrated with liver masses. Furthermore, SPAIR SSFSE is a crucial tool for the depiction of inflammatory processes in the abdomen, particularly IBD. By means of SPAIR T2-weighted SSFSE a differentiation between active and non-active inflammatory processes can be easily established.

Contact

Thomas C. Lauenstein, M.D.
 University Hospital Essen
 Dept. of Diagnostic and Interventional
 Radiology and Neuroradiology
 Hufelandstr. 55
 45122 Essen, Germany
 thomas.lauenstein@uni-due.de



9 Patient with active diverticulitis. There is increased T2-weighted signal in and adjacent to the wall of the sigmoid colon (arrow) in keeping due to edema.



10 T2-weighted SPAIR imaging can easily display not only an inflammatory process itself, but also complications such as a fluid-filled fistula – between bowel and cutis – (arrow).

References

- Gaa J, Hatabu H, Jenkins RL, Finn JP, Edelman RR. Liver masses: replacement of conventional T2-weighted spin-echo MR imaging with breath-hold MR imaging. *Radiology* 1996;200: 459–464.
- Florie J, Wasser MN, Arts-Cieslik K, Akkerman EM, Siersema PD, Stoker J. Dynamic contrast-enhanced MRI of the bowel wall for assessment of disease activity in Crohn's disease. *AJR Am J Roentgenol* 2006;186:1384–1392.
- Maccioni F, Bruni A, Viscido A, et al. MR imaging in patients with Crohn disease: value of T2- versus T1-weighted gadolinium-enhanced MR sequences with use of an oral superparamagnetic contrast agent. *Radiology* 2006;238:517–530.
- Martin DR, Danrad R, Herrmann K, Semelka RC, Hussain SM. Magnetic resonance imaging of the gastrointestinal tract. *Top Magn Reson Imaging* 2005;16:77–98.
- Nitta N, Takahashi M, Furukawa A, Murata K, Mori M, Fukushima M. MR imaging of the normal appendix and acute appendicitis. *J Magn Reson Imaging* 2005;21:156–165.
- Cobben LP, Groot I, Blickman JG, Puylaert JB. Right colonic diverticulitis: MR appearance. *Abdom Imaging* 2003;28:794–798.
- Heverhagen JT, Ishaque N, Zielke A, et al. Feasibility of MRI in the diagnosis of acute diverticulitis: initial results. *Magma* 2001;12:4–9.
- Heverhagen JT, Zielke A, Ishaque N, Bohrer T, El-Sheik M, Klose KJ. Acute colonic diverticulitis: visualization in magnetic resonance imaging. *Magn Reson Imaging* 2001;19:1275–1277.
- Birchard KR, Brown MA, Hyslop WB, Firat Z, Semelka RC. MRI of acute abdominal and pelvic pain in pregnant patients. *AJR Am J Roentgenol* 2005;184:452–458.
- Brown MA, Birchard KR, Semelka RC. Magnetic resonance evaluation of pregnant patients with acute abdominal pain. *Semin Ultrasound CT MR* 2005;26:206–211.
- Cobben LP, Groot I, Haans L, Blickman JG, Puylaert J. MRI for clinically suspected appendicitis during pregnancy. *AJR Am J Roentgenol* 2004;183:671–675.
- Tang Y, Yamashita Y, Takahashi M. Ultrafast T2-weighted imaging of the abdomen and pelvis: use of single shot fast spin-echo imaging. *J Magn Reson Imaging* 1998;8:384–390.
- Lauenstein TC, Sharma P, Hughed T, Heberlein K, Tudorascu D, Martin DR. Evaluation of optimized inversion-recovery fat-suppression techniques for T2-weighted abdominal MR Imaging. *J Magn Reson Imaging* 2008;27:1448–1454.
- Maccioni F, Bruni A, Viscido A, et al. MR imaging in patients with Crohn disease: value of T2- versus T1-weighted gadolinium-enhanced MR sequences with use of an oral superparamagnetic contrast agent. *Radiology* 2006;238:517–530.
- Udayasankar UK, Lauenstein TC, Martin DR. Role of Spectral Presaturation Attenuated Inversion-Recovery (SPAIR) T2 Fat-suppressed MR Imaging in Active Inflammatory Bowel Disease. *RSNA* 2007.