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Non-enhanced magnetic resonance imaging of the small bowel at 7 Tesla in comparison to 1.5 Tesla: First steps towards clinical application

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ABSTRACT

Objective: To perform non-enhanced (NE) magnetic resonance imaging (MRI) of the small bowel at 7 Tesla (7 T) and to compare it with 1.5 Tesla (1.5 T).
Material and methods: Twelve healthy subjects were prospectively examined using a 1.5 T and 7 T MRI system. Coronal and axial true fast imaging with steady-state precession (TrueFISP) imaging and a coronal T2-weighted (T2w) half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequence were acquired. Image analysis was performed by 1) visual evaluation of tissue contrast and detail detectability, 2) measurement and calculation of contrast ratios and 3) assessment of artifacts.
Results: NE MRI of the small bowel at 7 T was technically feasible. In the vast majority of the cases, tissue contrast and image details were equivalent at both field strengths. At 7 T, two cases revealed better detail detectability in the TrueFISP, and better contrast in the HASTE. Susceptibility artifacts and B_1 inhomogeneities were significantly increased at 7 T.
Conclusion: This study provides first insights into NE ultra-high field MRI of the small bowel and may be considered an important step towards high quality T2w abdominal imaging at 7 T MRI.

1. Introduction

Magnetic resonance imaging (MRI) of the small bowel has become a standard imaging technique in clinical routine to assess diseases of the small bowel such as inflammatory bowel diseases, tumors, or associated extraluminal manifestations [1–3]. In order to obtain as much information as possible on pathologic processes, the MRI protocol in clinical routine consists of a number of different sequence types. Contrast-enhanced T1-weighted imaging of the small bowel usually has priority over non-enhanced (NE) imaging because enhancement patterns allow for an appropriate classification of small bowel pathologies. However, analysis of NE images also provides important and sometimes even exclusive information [4–7]. In this context, true fast imaging with steady-state free precession imaging (TrueFISP) provides a general overview by means of a good delineation of the bowel wall as well as a good detectability of small mesentery structures. However, T2-weighted (T2w) half-Fourier acquisition single-shot turbo spin-echo imaging (HASTE) with fat saturation facilitates the verification of intramural edema of the bowel wall and small fluid collections in the mesentery fat tissue. This feature is required to estimate the grade of inflammatory activity. Therefore, the HASTE sequence represents a necessity for different inflammatory scoring systems [6,7].

Despite substantial progress in MRI, the diagnostic capability of small bowel MRI for morphological and functional assessment has not reached its full potential yet [8,9]. Among other technical advancements, MRI is moving towards higher field strengths to further improve spatial resolution, soft tissue contrast and image quality [10–12]. Some potential advantages of MRI at 7 T as to the depiction of abdominal structures were demonstrated in various pilot studies [13–16]. In particular, contrast-enhanced imaging of the small bowel at 7 T revealed promising results [16]. However, NE and especially T2w imaging of the abdomen at 7 T MRI remains

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challenging due to known B_1 inhomogeneities, limited available peak radiofrequency (RF) power, and specific absorption rate (SAR) limitations at this high magnetic field strength [17–19].

The possibilities of NE small bowel imaging at 7 T have not been explored so far. Thus, the aim of the present study is to investigate the technical feasibility and achievable image quality of NE MRI of the small bowel at 7 T. Furthermore, the results of 7 T MRI are intraindividually compared with small bowel imaging at 1.5 T.

2. Materials and methods

2.1. Study design and subjects

Twelve healthy volunteers (7 females, 5 males) with a mean age of 26.8 years (range: 21.5–31.8 years) and a mean body mass index of 22 (range 18.9–25.8) were enrolled in this prospective study. The study was approved by the local ethics committee. Written informed consent was obtained from all subjects.

2.2. Subject preparation

Subjects underwent MRI at 1.5 T and 7 T on two different days using an identical standard preparation protocol. Subjects fasted for at least 4 h before they commenced to drink 1 L of a locust bean gum/mannitol hydrosolution (Roeper, Hamburg, Germany) continuously over a period of ¾ h prior to the examination. Subjects were placed in a head first prone position into the MR systems.

2.3. MR system and MR imaging

Imaging was performed using a 1.5 T MR system (MAGNETOM Avanto; Siemens Healthcare GmbH, Erlangen, Germany) and a 7 T MR system (MAGNETOM 7 T; Siemens Healthcare GmbH, Erlangen, Germany), both equipped with similar gradient systems providing a maximum amplitude of 45 mT/m and a slew rate of 220 mT/m/ms. On the 1.5 T MR system a combination of a body-array surface receiver RF coil covering the whole abdomen/pelvis and an integrated spine array RF coil (total number of 24 RF coil elements) was used. All 7 T MRI scans were acquired with a custom-built 8-channel transmit/receive RF body coil and a custom 8-channel RF shimming system which is capable of fast switching between different RF shim sets for B_1 signal homogenization [17–19]. Calculations of individual RF shims were performed for each subject before commencing diagnostic 7 T MRI.

Imaging of the entire small bowel was performed at both MR systems with TrueFISP in coronal and axial orientations, and with T2w HASTE imaging in coronal orientation. Parameter details are presented in Table 1. In the TrueFISP sequence, the sensitivity to susceptibility artifacts was reduced by choosing minimal repetition time (TR), echo time (TE) and higher receiver bandwidths at 7 T. An RF excitation technique using time interleaved acquisition of modes (TIAMO) was applied for the 7 T HASTE sequence to reduce B_1 inhomogeneities [19]. Furthermore, slice-selective gradient reversal was applied for improved fat saturation [20]. A long TE of 298 ms yielded best background suppression and thereby improved contrast of the filled bowel.

2.4. Image analysis

All MR images were analyzed in consensus by two radiologists (14 and 8 years of experience in abdominal MRI) on a standard post-processing picture archiving and communications system (PACS) workstation (Centricity RIS 4.0i, GE Healthcare, USA).

For image evaluation, the small bowel was subdivided into jejunum and ileum. According to the known anatomy, the jejunum was defined as the 2/5 of the small bowel in the upper left abdomen and the ileum was determined as the 3/5 of the small bowel in the lower right abdomen.

2.4.1. Bowel distension

Distension of the small bowel was assessed as good (bowel wall and lumen distinguishable without restrictions), moderate (bowel wall and lumen distinguishable but some parts collapsed) or poor (almost completely collapsed small bowel). A good and moderate distension was defined as sufficient for a valid evaluation, whereas a poor distension was considered insufficient.

2.4.2. Qualitative rating of tissue contrast and details

For a qualitative assessment, tissue contrast and detectability of image details were evaluated on a three-point scale (1 = 1.5 T with superior tissue contrast; 2 = 1.5 and 7 T with equal tissue contrast; 3 = 7 T with superior tissue contrast) by direct and intraindividual comparison of the 7 T and 1.5 T images. Tissue contrast of the small bowel was assessed as to the differentiability between small bowel wall and lumen. Tissue contrast of the mesentery was evaluated by differentiation of vessels and lymph nodes from mesentery fat tissue. Detectability of image details was analyzed with regard to the visualization of small anatomical details (plicae circulares, septae of fat tissue, small vessels).

2.4.3. Quantitative assessment of tissue contrast

For quantitative assessment, signal intensity (SI) differences between small bowel lumen and small bowel wall were determined. To this end, regions of interest were placed into the lumen and adjacent bowel wall (ellipse, mean major axis 8.5 mm and mean minor axis 2.5 mm) of the jejunum and ileum. Based on these measurements, the contrast (C) of bowel wall versus bowel lumen was calculated according to the following equation: $C = (SI_{bl} - SI_{bw})/$

Table 1
Imaging parameters for the MRI protocol at 1.5 T and 7 T.

Sequence	cor. TrueFISP		ax. TrueFISP		cor. HASTE	
Field strength [T]	**1.5**	**7**	**1.5**	**7**	**1.5**	**7**
TR [ms]	3.94	4.18	3.94	4.47	1200	2500
TE [ms]	1.97	1.75	1.97	1.86	285	298
Flip angle [°]	69	60	69	60	150	180
Voxel size [mm^3]	1.6 × 1.6 × 3.0	0.8 × 0.8 × 2.0	1.6 × 1.6 × 3.0	0.7 × 0.7 × 2.0	1.6 × 2.1 × 6.0	1.0 × 1.0 × 5.0
Matrix read × phase	256 × 256	512 × 512	256 × 192	512 × 384	256 × 192	384 × 384
Slices	20	20	20	20	15	5
PAT	2	2	2	2	2	3
Bandwidth [Hz/px]	558	751	558	751	300	407
Turbo factor	–	–	–	–	192	384
TA [min:s]	0:13	0:26	0:11	0:20	0:18	0:25

Fat suppression for the HASTE sequence was achieved at 7 T by slice-selective gradient reversal, while at 1.5 T a standard spectral fat saturation was applied.