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Original Contribution

Colorectal carcinoma: Ex vivo evaluation using 3-T high-spatial-resolution quantitative T2 mapping and its correlation with histopathologic findings☆

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ABSTRACT

Purpose: In this study, we aimed to evaluate the feasibility of determining the mural invasion depths of colorectal carcinomas using high-spatial-resolution (HSR) quantitative T2 mapping on a 3-T magnetic resonance (MR) scanner.

Materials and methods: Twenty colorectal specimens containing adenocarcinomas were imaged on a 3-T MR system equipped with a 4-channel phased-array surface coil. HSR quantitative T2 maps were acquired using a spin-echo sequence with a repetition time/echo time of 7650/22.6–361.6 ms (16 echoes), 87 × 43.5-mm field of view, 2-mm section thickness, 448 × 224 matrix, and average of 1. HSR fast-spin-echo T2-weighted images were also acquired. Differences between the T2 values (ms) of the tumor tissue, colorectal wall layers, and fibrosis were measured, and the MR images and histopathologic findings were compared.

Results: In all specimens (20/20, 100%), the HSR quantitative T2 maps clearly depicted an 8-layer normal colorectal wall in which the T2 values of each layer differed from those of the adjacent layer(s) ($P < 0.001$). Using this technique, fibrosis (73.6 ± 9.4 ms) and tumor tissue (104.2 ± 6.4 ms) could also be clearly differentiated ($P < 0.001$). In 19 samples (95%), the HSR quantitative T2 maps and histopathologic data yielded the same findings regarding the tumor invasion depth.

Conclusions: Our results indicate that 3-T HSR quantitative T2 mapping is useful for distinguishing colorectal wall layers and differentiating tumor and fibrotic tissues. Accordingly, this technique could be used to determine mural invasion by colorectal carcinomas with a high level of accuracy.

1. Introduction

According to previous reports, histopathologic stage is strongly related to prognosis among patients with colorectal carcinoma [1,2]. In addition, accurate preoperative staging is an essential component of decision-making regarding individualized therapies for patients in this population. However, computed tomography (CT) cannot currently be used to assess the tumor invasion depth in the colorectal wall. Despite the development of multidetector CT and consequent improvement in local staging accuracy [3,4], the colorectal wall exhibits a poor soft-tissue contrast. As a result, it is nearly impossible to distinguish colorectal wall layers using existing technologies such as endoscopic ultrasound (EUS), which features many technical limitations in this area (e.g., limited range, artifactual echoes in the layer interfaces, high failure rate in stenotic tumors, and high operator dependency) [5–7].

In contrast to the abovementioned modalities, some reports have suggested the ability of magnetic resonance (MR) imaging in depicting mural invasion by colorectal carcinomas [8,9]. However, conventional MR imaging, which features limited spatial resolution, cannot distinguish individual colorectal wall layers [10–16]. To overcome this limitation as well as the visual and subjective nature of MR assessment, 1.5-T quantitative T2 mapping has been recommended for providing more objective assessments of rectal and prostate tumors [17,18].

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Although 3-T MR imaging, which features better spatial resolution and, therefore, an improved signal-to-noise ratio (SNR), has recently been applied to rectal tumors [19–21], we do not know of any reports that describe the use of this technology for high-spatial-resolution (HSR) quantitative T2 mapping of colorectal carcinomas. Accordingly, we aimed to use 3-T MR HSR quantitative T2 mapping to evaluate colorectal specimens containing adenocarcinomas. In this study, we aimed to calculate the T2 values of colorectal wall layers, tumors, and fibrotic tissue and evaluate the feasibility of this technique for determining the depths of mural invasion.

2. Materials and methods

2.1. Study population

For this study, we evaluated 20 surgical specimens, each containing histologically confirmed adenocarcinoma within normal colorectal tissue, that had been acquired from 20 consecutive patients (13 men, 7 women; mean age: 67 ± 9 years; range: 51–82 years) treated in our Department of Colorectal Surgery. All specimens were imaged after fixation in 10% formalin. Official approval for this study was provided by our institutional review board. All patients provided written informed consent prior to participating in this study.

In addition, we performed in-vivo MR imaging of a healthy volunteer (a 44-year-old man) to show that some of the colorectal layers can be distinguished in vivo.

2.2. Imaging technique

A 3-T MR imaging unit (Magnetom Spectra; Siemens, Erlangen, Germany), equipped with actively shielded gradients with a maximum strength of 33 mT/m, was used to perform HSR MR imaging. All measurements were collected using a 4-channel phased-array surface coil. After immersing the resected colorectal specimen in a container of water and placing the container on the surface coil, we set the HSR MR imaging orientation longitudinally along the long axis of the specimen.

HSR quantitative T2 maps were obtained using a spin-echo sequence with the following parameters: repetition time/echo time (TR/TE), 7650/22.6–361.6 ms (TEs used: 22.6, 45.2, 67.8, 90.4, 113, 135.6, 158.2, 180.8, 203.4, 226, 248.6, 271.2, 293.8, 316.4, 339, 361.6 ms); field of view (FOV), 87 mm × 43.5 mm; section thickness, 2 mm with a 1-mm intersection gap; matrix, 448 × 224; average, 1; and voxel size, 0.075 mm^3. HSR T2-weighted images were also obtained using a fast spin-echo sequence with the following parameters: TR/TE, 5000/91 ms; FOV, 87 mm × 43.5 mm; section thickness, 2 mm with a 1-mm intersection gap; matrix, 384 × 192; averages, 10; turbo factor, 12; parallel imaging factor, 2; and voxel size, 0.103 mm^3. The acquisition times were 51 min 40 s for the quantitative T2 maps and 12 min 37 s for the T2-weighted images.

In-vivo axial T2-weighted images were obtained using a 6-channel body matrix coil and the following fast spin-echo sequence: TR/TE, 5200/98 ms; FOV, 340 mm × 340 mm; section thickness, 4 mm with a 0.4-mm intersection gap; matrix, 512 × 333; average, 1; turbo factor, 12; parallel imaging factor, 2; and voxel size, 2.712 mm^3. The acquisition time was 2 min 38 s for the in-vivo T2-weighted images.

2.3. Image processing

When collecting T2 measurements, the first echo image from the multiple spin-echo sequence was excluded to minimize the error from stimulated echoes. Based on the signal intensity (SI) of the 15 other echo images, the following formula was used to calculate the T2 relaxation time (ms) on a pixel-by-pixel basis:

$$S = S_0 \exp(-TE/T2),$$

where S_0 is the initial SI, and S is the SI at TE (ms). SI, as a function of TE, was fitted using the monoexponential function for each pixel, and the T2 relaxation time was calculated from the slope of the best fit. Finally, quantitative T2 maps were generated by representing the calculated T2 relaxation time values on a gray-scale image.

2.4. Image analysis

Two observers who were blinded to the histologic analyses independently evaluated the MR images to determine the presence, SI, uniformity, and thickness of the colorectal wall layers. Disagreements regarding any findings were resolved via discussion and consensus. Subsequently, the colorectal carcinoma contour and SI were analyzed in each sample, and the depth of colorectal wall penetration by the tumor was determined according to the deepest invaded layer, with reference to the American Joint Committee on Cancer (AJCC) TNM classification [1,2]. The observers used abnormal configurations and SIs to distinguish carcinomas and colorectal wall layers as described previously [8]. The decision of the extent of tumor infiltration was made on both the T2-weighted images and T2 maps.

Using generated HSR quantitative T2 maps, regions of interest (ROIs) were drawn on colorectal wall layers, carcinomas, and fibrotic and adipose tissues. The size of the ROIs was approximately equivalent to the tumor cross-sectional area in colorectal carcinomas and to the thickness of each layer in the colorectal wall. The ROIs were positioned on the T2 maps using the T2-weighted images as references, and the conversion of the ROIs were performed on a pixel-by-pixel basis. A single observer drew and placed all ROIs. Three or 4 ROIs were placed over the tumor and each layer per sample, and the mean values of all ROIs were calculated for each tumor and layer to generate quantitative data, using the ImageJ 1.47 software program (National Institutes of Health, Bethesda, MD, USA). Finally, the MR findings of all 20 specimens were compared with the corresponding histologic findings on a slice-by-slice basis using visual and spatial matching according to anatomic features (including blood vessels and contour details).

2.5. Histologic preparation and examination

Following HSR MR imaging, each specimen was sectioned longitudinally such that the MR images and histologic sections would correspond. The sections were then paraffin-embedded and cut into 6-μm-thick slices with a microtome. After staining with periodic acid-Schiff (PAS), elastica-van Gieson (EVG), and hematoxylin-eosin (H-E), a single experienced pathologist who was blinded to the MR results evaluated all specimens to determine the depths of tumor invasion into the colorectal wall layers.

2.6. Statistical analysis

The means ± standard deviations (SD) of T2 values in the colorectal wall layers, carcinomas, and fibrotic and adipose tissues were calculated from the HSR quantitative T2 maps, and these data were subjected to a statistical analysis using the IBM SPSS Statistics package, version 20 (IBM SPSS Japan, Tokyo, Japan). Differences in T2 values among the carcinomas, colorectal wall layers, and fibrotic and adipose tissues were determined using Tukey's test or Dunnett's test, where appropriate. A P value of <0.05 was considered to indicate a statistically significant difference.

3. Results

3.1. SI of the normal colorectal wall layers on HSR MR images

The SIs of normal colorectal wall layers on HSR MR images are presented in Table 1 and Fig. 1. The HSR quantitative T2 maps of all 20 colorectal specimens (100%) could clearly resolve each normal colorectal