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Preoperative staging of rectal cancer: accuracy of 3-Tesla magnetic resonance imaging

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Abstract The purpose of this study was to evaluate the accuracy of 3-Tesla magnetic resonance imaging (MRI) for the preoperative staging of rectal cancer. Thirty-five patients with a primary rectal cancer who underwent preoperative 3-T MRI using a phased-array coil and had a surgical resection were enrolled in the study group. Preoperatively, three experienced radiologists independently assessed the T and N staging. A confidence level scoring system was used to determine if there was any perirectal invasion, and receiver operating characteristic (ROC) curves were generated. The interobserver agreement was estimated using κ statistics. The overall accuracy rate of T staging for rectal cancer was 92%. The diagnostic accuracy was 97% for T1, 89% for T2 and 91% for T3, respectively. The predictive accuracy for perirectal invasion by the three observers was high (Az>0.92). The interobserver agreement for T staging was moderate to substantial. The overall sensitivity, specificity, and accuracy for the detection of mesorectal nodal metastases were 80%, 98%, and 95%, respectively. In conclusion, preoperative 3-T MRI using a phase-array coil accurately indicates the depth of tumor invasion for rectal cancer with a low variability.

Keywords Rectum · Neoplasms · MR imaging · High-field-strength imaging · Preoperative staging

Introduction

Rectal cancer is a common cancer and a main cause of mortality in Western countries. The prognosis of rectal cancer is directly related to a number of factors, such as the depth of tumor invasion into and beyond the bowel wall [1], number of lymph node metastases [2], and involvement of the circumferential resection margin (CRM) [3–6]. Therefore, an accurate preoperative assessment of rectal cancer is essential for adequate management because the treatment strategies need to be individualized according to the tumor invasion depth and the status of the regional lymph nodes, which include transanal local excision, transanal endoscopic microsurgery (TEM), total mesorectal excision (TME), and preoperative irradiation with or without chemotherapy [7, 8]. The treatment strategies used are as follows: local excision or TEM (mainly stages ≤T1), TME (mainly stage T2 and T3), and a long course of preoperative (chemother-

Table 1 Tumor invasion and lymph node metastases according to MRI and histopathology by three observers

Histopathology					
MRI	T	T1 (*n*=8)	T2 (*n*=7)	T3 (*n*=20)	Total (*n*=35)
Observer 1	T1	7			7
	T2	1	7	2	10
	T3			18	18
Observer 2	T1	7			7
	T2	1	6	3	10
	T3		1	17	18
Observer 3	T1	7			7
	T2	1	5	1	7
	T3		2	19	21
Histopathology					
MRI		N0 (*n*=19)	N1 (*n*=7)	N2 (*n*=4)	Total (*n*=30)
Observer 1	N0	18	1		19
	N1	1	6		7
	N2			4	4
Observer 2	N0	17			17
	N1	2	6	1	9
	N2		1	3	4
Observer 3	N0	17			17
	N1	2	6	1	9
	N2		1	3	4

apeutic) radiation therapy, aimed at downsizing and downstaging tumors (mainly stage T4) [9].

Noninvasive radiological modalities, such as transrectal ultrasonography (TRUS), computed tomography (CT), and magnetic resonance (MR) imaging (MRI) are diagnostic tools widely used for assessing the invasion depth and/or lymph node involvement, but their reported diagnostic accuracy varies. MRI is one of the most promising techniques for the local staging of rectal cancer. Improvements in the performance of the MRI of rectal cancer has improved with the advent of a dedicated phased-array coil, as expected [10–13]. Recently, although the application of a new generation of phased-array coils at 1.5 T, the accuracy for T staging has not been as high as expected, varying between 65% and 86%, and the reproducibility of the results has been less than satisfactory [12, 14]. The causes that most often occur with phased-array MRI at 1.5 T are the differentiation between T2 and borderline T3 lesions with overstaging. Preoperatively accurate diagnosis of superficial tumors is crucial because of candidates for local excision. Until now, however, phased-array MRI at 1.5 T has limitations for the assessment of superficial tumors due to insufficient differentiation of rectal wall layers. Although some studies reported that endorectal MRI could be as accurate as TRUS for staging of superficial tumors, TRUS is known to be the most accurate staging tool for superficial rectal tumors [15, 16].

More recently, whole-body MR scanners at high field strength (3 T) have been introduced. Generally, a higher field strength increases the signal-to-noise ratio (SNR), which can increase the spatial or temporal resolution of the MR measurements [17, 18]. Therefore, we hypothesized that further shorter examination times, due to improved temporal resolution, thin slices of high resolution, higher matrix, and an increased SNR of the pelvic cavity using 3-T MRI, can potentially improve the anatomical detail over 1.5-T MRI, which can improve the differentiation of rectal wall layers and the staging of rectal cancer. Accordingly, this study evaluated the accuracy of 3-T MRI for the preoperative staging of rectal cancer.

Materials and methods

Institutional Review Board approval was obtained for this study, and informed consent to review their patients' medical records for research purposes was obtained. Between November 2004 and July 2005, 62 consecutive patients underwent rectal MRI at 3 T using a phased-array coil. Of the 62 patients, 35 [20 men, 15 women; age range

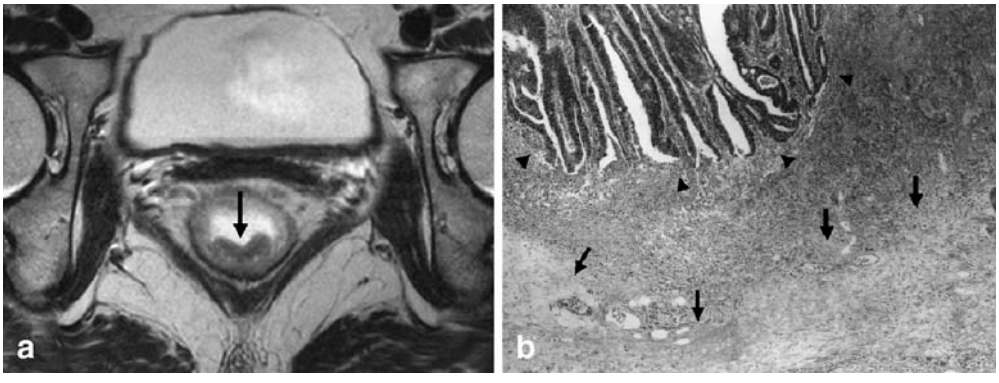

Fig. 1a, b T1-stage rectal cancer in a 56-year-old woman. **a** Axial T2-weighted turbo spin-echo MRI demonstrates a tumor (*arrow*) confined to the submucosal layer. **b** Photomicrograph of a histopathologic specimen shows the tumor (*arrowheads*) limited to the submucosal layer without invading adjacent muscle layer (*arrows*) (hematoxylin-eosin stain; ×40)

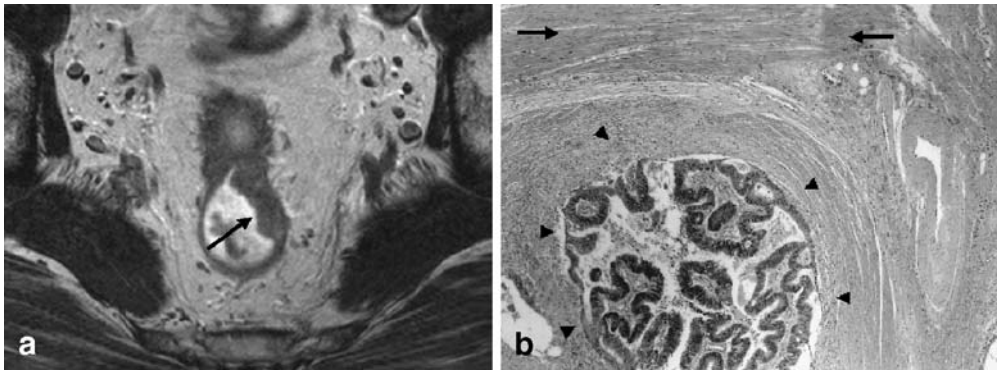

Fig. 2a, b T2-stage rectal cancer in a 53-year-old man. **a** Axial T2-weighted turbo spin-echo MRI demonstrates a tumor (*arrow*) extending into the muscular layer, with a loss of the interface between the submucosa and muscle layer. **b** Photomicrograph of a histopathologic specimen, showing that the tumor (*arrowheads*) extends into the circular muscular layer, but does not penetrate the outer muscular layer (*arrows*) (hematoxylin-eosin stain; ×40)

45–74 years (mean 57 years)] were proven histopathologically to have rectal adenocarcinoma by surgery and were enrolled in this study: 29 patients underwent anterior resection with TME, one patient underwent Miles' operation with TME, and the remaining five patients underwent TEM. The remaining 27 patients were excluded because they had either received preoperative radiation or chemotherapy (n=13), refused surgery (n=7), inoperability (n=5), anal fistula (n=1), and endometriosis in the rectum (n=1). All MR examinations were performed up to 14 days prior to surgery.

MR techniques

A total of 35 patients underwent MRI with a 3.0-T whole-body system (Intera Achieva 3T, Philips Medical Systems, Best, The Netherlands) using a dedicated cardiac SENSE coil (six elements phased-array coil), with 80 mT/m and a slew rate of 200 T/m/s. No intravenous antiperistaltic agent was administered. The patients were asked to perform rectal cleansing 2–3 h prior to the MR examination using two rectal suppository pills (bisacodyl, Dulcolax suppository; Boeringer Ingelheim Korea, Chung Ju, Korea). In the MR room, warm water was administered using a balloon-tipped rectal tube, and the rectum was filled until the patient's rectum felt full. The volume of water ranged from 150 to 400 ml. The rectal tube was removed after instillation.

First, a coronal localizing image was obtained to select the axial and sagittal images with a T2-weighted turbo spin echo (TSE) sequence (repetition time ms/echo time ms, 2,500–5,000/100; echo train length of six, 5-mm slice thickness, 1-mm gap, 256×256 matrix, 24-cm field of view, two signals acquired, SENSE factor of two, and sequence duration of 3–5 min). The sagittal images were used to plan the thin-slice axial and coronal imaging. The axial and coronal T2-weighted TSE (2,500–5,000/100, echo train length of six, 3 mm slice thickness, 1-mm gap, 312×312 matrix, 18-cm field of view, four signals acquired, SENSE factor of two, 1-mm^3 voxel size, and sequence duration of 3–4 min) was angled perpendicular to the long axis of the rectal cancer. Finally, an axial T1-weighted TSE sequence (656/10, echo train length of five, 5-mm slice thickness, 1-mm gap, four signals acquired, 256×256 matrix, 24-cm field of view, and sequence duration of 4–5 min) was acquired. All sequences were obtained with no fat saturation. The total examination time ranged from 19 to 22 min.

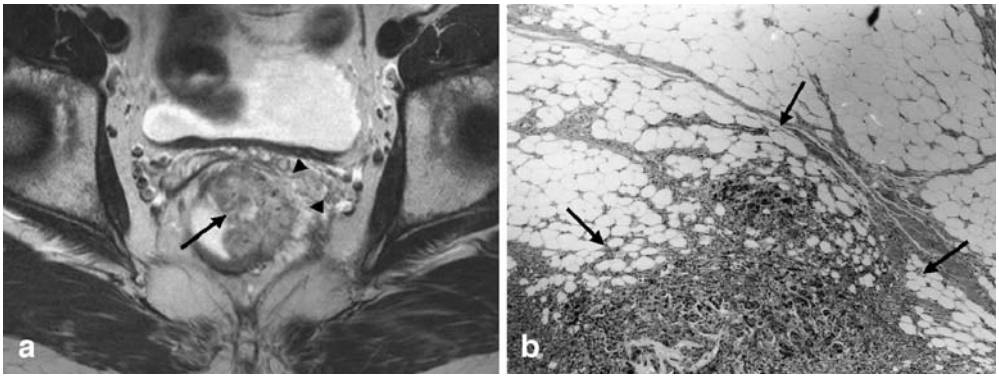

Fig. 3a, b T3-stage rectal cancer in a 54-year-old man. **a** Axial T2-weighted turbo spin-echo MRI demonstrates a tumor (*arrows*) extends through the muscle layer into the perirectal fat (*arrowheads*). **b** Photomicrograph of a histopathologic specimen showing that the tumor penetrates the muscular rectal wall. Tumor cells are seen in perirectal adipose tissues (*arrows*) (hematoxylin-eosin stain; ×40)

Table 2 Prediction of the sensitivity, specificity, and accuracy of staging at 3-T MRI by three different observers (data are percentages)

		Observer 1	Observer 2	Observer 3	Mean
T1 (*n*=8)					
	Sensitivity	88	88	88	88
	Specificity	100	100	100	100
	Accuracy	97	97	97	97
T2 (*n*=7)					
	Sensitivity	100	85	71	86
	Specificity	89	86	93	89
	Accuracy	91	86	89	89
T3 (*n*=20)					
	Sensitivity	90	85	95	90
	Specificity	100	93	87	96
	Accuracy	94	89	91	91
Total (*n*=35)	Mean accuracy	94	90	92	

Image interpretation

Three experienced observers (S.H.K., D.C., and M.J.K., with 10, 5 and 3 years' experience in MRI, respectively), who were blinded to each other and to the histopathologic results, examined the MR images (i.e., T and N stage, perirectal invasion of rectal cancer using a confidence level scoring system) prospectively. All the MR images were read and reviewed using a 2,000×2,000 Picture Archiving and Communication Systems monitor (Pathspeed workstation; GE Medical Systems, Milwaukee, Wis.) with an adjustment of the optimal window settings in each case. Recently, identifying the CRM in rectal cancer that is an important predictor for the local recurrence rate has been stressed. In our study, however, we did not assess the CRM, but instead T staging. The overall staging of the rectal tumors is as follows, and we used these as T-staging criteria: T1 (the tumor signal intensity is confined to the submucosal layer and has a relatively low signal compared with the high signal intensity of the surrounding submucosa), T2 (the tumor signal intensity extends to the muscle layer leading to an irregular or thickened muscle layer, but without perirectal infiltration), T3 (the tumor signal intensity extends through the muscular layer into the perirectal fat, or an angiolymphatic tumor invasion in the mesorectum), and T4 (the tumor signal intensity extends to the adjacent organ, mesorectal fascia or bowel). Most staging failures with MRI occur in the differentiation of T2-stage and borderline T3-stage lesions, mainly due to overstaging. Therefore, to assess the differentiation between T2 and T3 staging, three observers scored the MR images independently for tumor penetration into the perirectal fat using a confidence level scoring system. The appearance of nodules, an interruption of the outer wall of the rectum, or an irregularly thickened spiculation but not fine spiculations, were considered to be indicators of a perirectal invasion. With respect to these findings, the following confidence levels for T3 staging were used: 1, definitely absent; 2, probably absent; 3, possibly present; 4, probably present; and 5, definitely present. Instead of using the size criteria, the criteria for regional nodal metastasis were defined as any size of an indistinct border or irregular margin or mixed signal intensity [19].

Histopathological examination

After TME, the circumferential resection plane of the specimen was inked, each specimen was opened along the anterior border proximal to the tumor-containing segment and the tumor itself was not touched. Before formalin fixation of the specimens, a radiologist (C.K.K.) and dedicated pathologist (S.Y.S.) with more than 10 years' experience in gastrointestinal pathology harvested the lymph nodes in the mesorectum. A radiologist (C.K.K.) and pathologist (S.Y.S.) assessed a lesion for lymph nodes in the pathologic room. The spatial correlation of the lymph nodes was achieved by identifying the anatomic and morphological landmarks between the specimens and MR images. Preoperatively, three different radiologists (M.J.K., D.C., and J.L.), at different times, marked at MRI lymph nodes suspected as metastases. These results were recorded by a radiologist (C.K.K.) for each patient. Finally, a

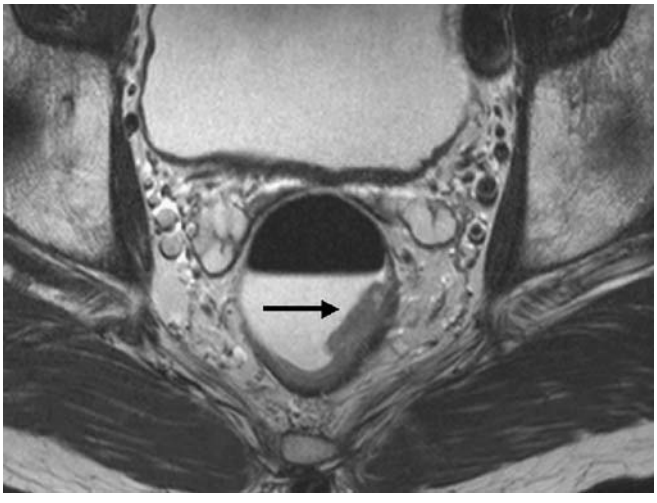

Fig. 4 T1-stage rectal cancer overstaged as a T2-stage tumor at MRI in a 53-year-old man. Axial T2-weighted turbo spine-echo image shows a tumor (*arrow*) with focal loss of the interface between the submucosa and muscle layer. Two out of three observers regarded this lesion as a T2 tumor. However, a histopathology examination revealed this tumor to be a T1 tumor

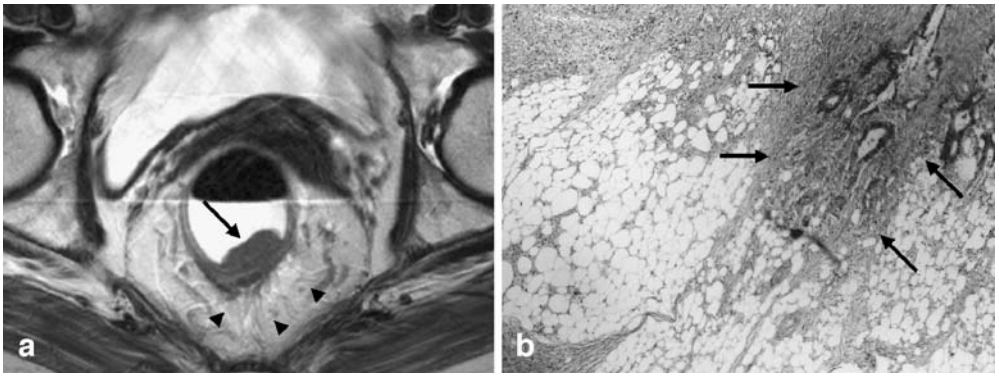

Fig. 5a, b T3-stage rectal tumor understaged as a T2-stage tumor at MRI in a 75-year-old woman. **a** Axial T2-weighted turbo spin-echo image shows a tumor (*arrow*) with fine perirectal spiculations (*arrowheads*). All three observers staged this tumor as T2 according to our diagnostic criteria. **b** However, photomicrograph of histopathologic specimen shows that the fine perirectal spiculations demonstrate desmoplastic reaction with tumor cells (*arrows*) (hematoxylin-eosin stain; ×40)

radiologist (C.K.K.) who knew the pathologic findings assessed the lymph nodes by the correlation with pathologic findings.

Each specimen was then fixed by total immersion in buffered formalin for 48 h. Each specimen was sliced transversely at 3-mm intervals, which is the same technique used for preoperative MRI. The extent of the local tumor staging in each slice was assessed according to the tumor component of the TNM system.

Statistical analysis

The accuracy of the three observers in rectal cancer staging was calculated based on a histopathologic examination. The sensitivity, specificity, and accuracy of T staging for rectal cancer were calculated. And the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the N staging for rectal cancer were also calculated. The observer performance for predicting a perirectal invasion was examined by analyzing the receiver operating characteristics (ROC) curve. The diagnostic accuracy was measured using the area under the ROC curve (Az). The Az values were compared to determine any differences in diagnostic performance using the Hanley and McNeil method [20]. The Az, 95% confidence intervals (CIs), sensitivity, specificity, and accuracy of each observer were calculated for the diagnoses of perirectal invasion, with decision threshold scores from 3 to 5 being considered positive for a diagnosis.

The interobserver agreement for the T and N staging for the whole rectal tumors was evaluated using linear weighted κ statistics [21]. The range of κ values can extend from 0 (no agreement) to 1.00 (perfect agreement) and can be interpreted as poor (0), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00). Statistical analysis was performed using the SPSS for Windows package, release 10.0 (SPSS, Chicago, III.). *P* values less than 0.05 were considered to indicate a significant difference.

Results

Table 1 summarizes the correlation between MRI and histopathology for T and N staging. All 35 rectal cancers were identified on the MR images. In all patients, the MRI allowed the visualization and delineation of the layers of both the rectal wall (mucosa, submucosa, proper muscle) and mesorectal fascia.

T staging

The histopathologic examination revealed eight T1 tumors, seven T2 tumors, and 20 T3 tumors (Figs. 1, 2, 3). No T4 tumor was found in any of the surgical specimens. Table 2 shows the sensitivity, specificity, and accuracy of the three observers using MRI to determine the T stage. The accuracy, sensitivity, and specificity of T1, T2, and T3 tumors were high, particularly suggesting the improvement of staging in T1 and T2. The mean overstaging and understaging of rectal cancer by the three observers was 6%. Observer 1 overstaged one tumor from T1 to T2 and

Table 3 Prediction for performance in depicting the perirectal invasion of rectal cancers between three different observers at 3-T MRI

	Observer 1	Observer 2	Observer 3
Az[a]	0.973	0.927	0.920
95% CI	0.853, 0.995	0.786, 0.986	0.777, 0.983
Sensitivity (%)	90	85	95
Specificity (%)	100	93	87

[a]There was no significant differences between Az values

Table 4 Prediction of nodal metastases of rectal cancers between three different observers in 257 nodes detected by 3-T MRI (numbers *in parentheses* are raw data; *PPV* positive predictive value, *NPV* negative predictive value)

	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Observer 1	78 (31/40)	98 (213/217)	89 (31/35)	96 (213/222)	95
Observer 2	80 (32/40)	98 (212/217)	86 (32/37)	96 (212/220)	95
Observer 3	83 (33/40)	97 (211/217)	85 (33/39)	97 (211/218)	95
Mean (%)	80	98	86	96	95

understaged two tumors from T3 to T2. Observer 2 overstaged two tumors, T1 to T2 and T2 to T3. Three tumors were understaged from T3 to T2. Observer 3 overstaged three tumors (T1 to T2, n=1; T2 to T3, n=2). One tumor was understaged from T3 and T2. T1 tumors were overstaged to T2 because of focal loss or mild irregularity of the interface between the submucosa and proper muscle layer (Fig. 4). Understaging from T3 to T2 tumors resulted from desmoplastic reaction, mimicking perirectal tumor invasion (Fig. 5).

Table 3 shows the Az values with the 95% CIs, sensitivity and specificity for predicting a perirectal invasion of three observers. The Az values in all three observers were high (>0.92), and sensitivity and specificity for predicting perirectal invasion were high. There was no significant difference among the Az values in three observers.

The interobserver agreement for T staging is as follows: observer 1 versus observer 2, κ=0.55; observer 2 versus observer 3, κ=0.80; observer 1 versus observer 3, κ=0.63). The interobserver agreement for determining the presence of perirectal invasion was moderate to substantial.

N staging

At histopathologic examination, the number of lymph nodes in each specimen varied from three to 26 (mean, 11.5). A total of 310 lymph nodes were revealed in 30 patients. Of these, 53 lymph nodes, all less than 3 mm in diameter, were not identified on the MR images. A total of 257 lymph nodes were available for evaluation of their MR images for predicting nodal metastases. Nineteen lymph nodes detected on MRI were not identified at histopathologic examination; all measured less than 3 mm in maximal diameter. Forty (16%) out of 257 nodes were node positive at the histopathologic examination. Twenty-four patients had N0, seven patients had N1, and four patients had N2. Table 4 shows the accuracy, sensitivity, specificity, PPV, and NPV in predicting a nodal metastasis from the MR images. The mean sensitivity, specificity, PPV, NPV, and accuracy of MRI in predicting nodal metastases were 80%, 98%, 86%, 96%, and 95%, respectively. The interobserver agreement in evaluating the nodal metastases is as follows: observer 1 versus observer 2, κ=0.63; observer 2 versus observer 3, κ=0.72; observer 1 versus observer 3, κ=0.51. The interobserver agreement for determining the presence of regional lymph node metastasis was moderate to substantial.

Discussion

Whole-body MR scanners at high field strength have been introduced in expectation of a larger SNR due to higher signal intensity, but with a decrease in the length of time required to obtain images being the most significant benefit [17, 18, 22]. High-field-strength MRI demonstrated the improvement of susceptibility-dependent imaging, chemical shift selective imaging and spectroscopy. However, high field strength might lead to undesired inhomogeneities of radiofrequency field inside the body [23]. Abdomen and sometimes pelvis is affected by the dielectric effects [24]. The current quality of abdominal and pelvis MR images recorded at 3 T is not always superior to examinations with optimized array coil systems on modern MR units at 1.5 T.

With the advent of phased-array MRI technique at 1.5 T, the accuracy of T-staging for rectal cancer has been more improved than body-coil MRI. However, it is far from perfect and there is substantial in inter- or intraobserver variability. Most staging failures occurred in the differentiation between T2 and borderline T3 lesions [11, 14, 25]. The reason for this was the diifculty in deciding whether perirectal spiculation was due to only a desmoplastic reaction or tumor infiltration. In our study, the accuracy for T3 tumors at 3-T MRI using a phased-array coil was 91%, which was similar to that obtained using 1.5-T MRI with a phased array coil [11, 12, 26]. The interobserver agreement for determining the presence of perirectal invasion of rectal cancer was moderate to substantial in three observers.

In comparison with the T2 stage or beyond, accurate evaluation for the T1 stage may indeed be valuable, because it can be treated by TEM. In differentiating the T1 and T2 stages, TRUS and 1.5-T MRI with an endorectal coil are the most accurate modalities [15, 16]. However, these modalities still have some problems. The major limitation of endorectal MRI and TRUS is the narrow field of view. Moreover, the positioning of an endoluminal device can be difficult or impossible in patients with high or stenosing tumors. In our study, 3-T phased-array MRI could delineate well the rectal wall layers in all patients and the results suggested a 97% and 89% accuracy for T1 and T2 stage, respectively, which is superior to that reported for endorectal 1.5-T MRI and comparable to TRUS [25, 27–29]. This suggests that phased-array 3-T MRI can play an important role in improving the accuracy of detecting superficial tumors. However, there may be a potential pitfall in the prediction of T1 superficial tumors. In our study, T1 tumors were overstaged to T2 because of focal

loss or mild irregularity of the interface between the submucosa and proper muscle layer (Fig. 4). We think that slightly oblique scanning of the rectum by the MR scanner may be a cause and on analyzing MR images an understanding of the geometry of the rectum course could decrease the errors.

TRUS and endorectal MRI have limited use in evaluating a locally advanced tumor, particularly involvement of the mesorectal fascia or surrounding pelvis structures [30]. Although the tumor stage is an important prognostic factor, preoperative assessment is of little benefit when it does not affect preoperative or operative management. By contrast, it has been shown repeatedly that prediction of the CRM (ie, the shortest distance from tumor to mesorectal fascia) is the most powerful factor for the local recurrence rate. Several studies reported that phased-array MRI at 1.5 T is highly accurate and reliable prediction of the CRM [14, 31]. A recent study reported that the contour of the mesorectal fascia was subject to impression by other nearby visceral organs. There is great individual variation in the amount of mesorectal fat, and in morphometric parameters between the male and female [32]. In our study, owing to the improvement of SNR and spatial resolution, 3-T MRI with a dedicated phased-array coil showed a high performance in predicting the accuracy of superficial rectal cancer. Although we did not evaluate the CRM for rectal cancer, however, according to our results at 3-T MRI, it might be hypothesized that the performance at 3-T MRI is at least comparable with the high performance of 1.5 T for the CRM. In a future study, the prediction of CRM at 1.5-T and 3-T phased-array MRI should be performed.

Although 3-T MRI could improve the spatial and temporal resolution, the main problem with the local staging of rectal cancer is overstaging and understaging. At 1.5 T, the overstaging of rectal cancer was reported to be 67–75% for T1, 25–46% for T2, and 4–50% for T3. In addition, understaging has been reported in 0–25% of T2 tumors and 0–9% of T3 tumors [12, 25]. In our study, however, the mean overstaging rate for rectal cancer at 3 T MRI using a phased-array coil in all three observers was 6% in that T1 and T2 were overstaged to T2 and T3, respectively. The mean understaging was 6% in all three observers with T3 as understaged as T2 (Fig. 5). Therefore, 3-T MRI using a phased-array coil decreased the overstaging and understaging rates as a result of the improved spatial resolution and depiction of the rectal wall layer.

Identifying nodal metastases is still a diagnostic problem for a radiologist. Accurately evaluating the preoperative staging of the lymph nodes in rectal cancer is crucial because the number of nodal metastases influence the patient's prognosis, and the presence of nodal metastases near the mesorectal fascia increases the risk of a recurrence [33]. Until now, the diagnostic criteria for nodal metastases vary. Some authors regard any visible node in the perirectal fast as being positive, while others use size criteria with a range of 3–10 mm [34, 35]. However, there is no consensus as to the size criteria for enlarged nodes and each institution uses different size criteria for predicting metastatic nodes. Recently, Brown et al. [19] demonstrated that an irregular border or mixed signal intensity of lymph nodes on MRI can improve the predictability of nodal metastases regardless of the size of the lymph nodes. Despite the identification of lymph nodes as small as 2–3 mm on high-spatial-resolution images, the detection of nodal metastases is still unreliable. In this study, even though the spatial resolution at 3-T MRI using a phased-array coil was better, the sensitivity and specificity of nodal metastases was 80% and 98%, respectively, and was similar to that at 1.5 T [19, 25]. The reason for this was that the morphological criteria used in this study might make it difficult to differentiate between reactive and metastatic nodes. Recently, MRI using ultrasmall superparamagnetic iron oxide (USPIO) contrast agents has shown promising results for staging nodal metastases [36]. The use of USPIO causes a shortening of the T2* relaxation time and in a decrease in signal intensity on the gradient-echo images of normal lymph nodes due to the increase in the number of susceptibility artifacts. In particular, the advantage of USPIO is that it can detect a focal nodal metastasis ≥1 mm. However, the value of MRI using USPIO in making an accurate nodal staging of rectal cancer needs to be determined using a larger study group.

There were some limitations of this study. First, this study examined a small population, particularly a small number of T1 and T2 lesions. Although the accuracy was high, in order to more accurately assess the staging of rectal cancer in T1 or T2 lesions, further studies with a larger population of patients will be needed and a comparative study using TRUS needs to be performed. Second, no comparisons are made with 1.5-T MRI in the same patients. Third, imaging protocols in this study were used similarly as those at 1.5 T. Therefore, the benefit from higher spatial resolution at 3 T was not really obtained. In future study, the optimization of imaging protocols in order to improve spatial resolution and increase SNR will be needed. Finally, no attempt was made to assess 3-T MRI in terms of clinical decision-making (for example, prediction of circumferential resection margin involvement, ability to predict sphincter sparing surgery etc.).

Notwithstanding these limitations, preoperative 3-T MRI using a dedicated phased-array coil accurately indicates the depth of tumor invasion with a low variability for rectal cancer.

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