Radiology

ORIGINAL RESEARCH • GASTROINTESTINAL IMAGING

Submucosal Enhancing Stripe as a Contrast Material–enhanced MRI-based Imaging Feature for the Differentiation of Stage T0–T1 from Early T2 Rectal Cancers

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See also the editorial by Turkbey in this issue.

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Background: Accurate differentiation of stage T0–T1 rectal tumors from stage T2 rectal tumors facilitates the selection of appropriate surgical treatment. MRI is a recommended technique for local staging, but its ability to distinguish T1 from T2 tumors is poor.

Purpose: To explore the value of a submucosal enhancing stripe (SES), an uninterrupted enhancing band between the rectal tumor and the muscular layer on contrast material–enhanced T1-weighted images, as a potential imaging feature to differentiate T0–T1 from T2 rectal tumors.

Materials and Methods: This retrospective study included patients with pT0–T1 and pT2 rectal tumors who underwent pretreatment MRI and rectal tumor resection between January 2012 and November 2019. Two radiologists independently evaluated tumor characteristics (SES; status of muscularis propria [SMP]; and tumor shape, location, and size) at MRI. The associations of clinical and imaging characteristics with stage T0–T1 or T2 tumors were assessed, β values were calculated, and predictive models were built. The diagnostic accuracies for the differentiation of T0–T1 tumors from T2 tumors with SES and SMP were compared.

Results: Data from 431 patients (mean age, 60 years ± 10 [standard deviation]; 261 men) were evaluated. SES (β = 3.9; 95% CI: 3.1, 4.7; $P < .001$), SMP (β = 1.3; 95% CI: 0.7, 1.9; $P < .001$), and carpetlike shape (β = 1.6; 95% CI: 0.5, 2.8; $P = .01$) were independent factors distinguishing T0–T1 tumors from T2 tumors. The diagnostic accuracy was 87% (95% CI: 84, 90; 376 of 431) for SES and 67% (95% CI: 63, 72; 290 of 431) for SMP ($P < .001$).

Conclusion: Submucosal enhancing stripe (SES) at contrasted-enhanced MRI, status of muscularis propria (SMP) on T2-weighted images, and tumor shape can serve as independent imaging features to differentiate stage T0–T1 rectal tumors from stage T2 rectal tumors. Moreover, SES is a more accurate feature than is SMP.

Online supplemental material is available for this article.

In recent years, early-stage rectal cancers have been found more commonly because of an increase in colorectal cancer screening. Total mesorectal excision has been widely adopted, with improvement in patient outcomes. Unfortunately, substantial risk for perioperative morbidity, such as sexual dysfunction or permanent stoma, accompanies this radical procedure (1,2). Therefore, minimally invasive local excision is usually suggested for rectal adenomas and well-selected stage T1 tumors; local excision in combination with chemoradiotherapy is used in patients with high-risk stage T1 cancers (3,4), while stage T2 tumors are usually treated with total mesorectal excision (3–6).

To determine the most appropriate treatment option, differentiation of stage cT1 cancer from stage cT2 cancer is of particular importance (7–9). Endoscopic US is considered more accurate than MRI in the staging of intramural lesions (10,11). However, this technique has limitations in the evaluation of more advanced tumors because of its narrow field of view compared with that of MRI. Moreover, its accuracy depends highly on sonographer experience (12,13). Although the National Comprehensive Cancer Network suggests both MRI and endoscopic US for clinical staging, MRI is preferred (14). In some institutions, individuals with newly diagnosed rectal cancer undergo MRI, whereas endoscopic US is recommended for those showing intramural lesions at MRI (15,16). However, this strategy is associated with a longer waiting time and higher expenditure.

At present, staging MRI is largely performed with T2-weighted imaging, which is considered a better sequence for

Abbreviations

SES = submucosal enhancing stripe, SMP = status of muscularis propria

Summary

Submucosal enhancing stripe at contrast material–enhanced MRI is a prospective imaging feature that enables differentiation of stage T0–T1 rectal tumors from stage T2 rectal tumors.

Key Results

- The frequency of a submucosal enhancing stripe (SES) at contrast material–enhanced MRI was different between stage T0–T1 and stage T2 rectal tumors (SES was present in 84% of T0–T1 tumors vs 8% of T2 tumors; $P < .001$).
- The accuracy of differentiation of stage T0–T1 rectal tumors from T2 rectal tumors for presence of SES was higher than that obtained by using the status of muscularis propria (87% vs 67%; $P < .001$).

delineating rectal wall layers (10,17). Regularity or irregularity of the muscularis propria is the major criterion for distinguishing stage T0–T1 from stage T2 with T2-weighted imaging (11,18). However, focal loss or mild irregularity of the muscularis propria can occur, resulting in high overstaging rates of 69%–95% (11,17,19,20). Contrast material–enhanced MRI is generally considered unnecessary for tumor staging because identification of individual rectal wall layers is still difficult (10,21). However, the reports of these studies did not mention the status of submucosal enhancing stripe (SES), an uninterrupted enhancing band between the rectal tumor and the muscular layer (10,21). Because submucosa contains abundant blood vessels, the status of SES may indicate the incidence or extent of tumor invasion. To our knowledge, no studies have evaluated the benefit of using SES as an imaging feature in the differentiation of stage T0–T1 from stage T2 rectal tumors.

Therefore, the purpose of this study was to explore the value of SES in the differentiation of stage T0–T1 rectal lesions from stage T2 rectal lesions and to compare the diagnostic ability to differentiate T0–T1 tumors from T2 tumors using SES at contrast-enhanced MRI with the diagnostic ability to differentiate these tumors using the status of muscularis propria (SMP) at T2-weighted imaging.

Materials and Methods

Study Population

We retrospectively reviewed the medical records of 3716 consecutive patients who underwent prospective rectal MRI from January 2012 to November 2019. Our institutional review board approved this retrospective study and waived the requirement for informed consent. Patients with primary rectal adenomas or rectal adenocarcinomas who had not previously received treatment and who underwent elective tumor resection within 3 weeks of undergoing MRI were eligible for this study. Patients were excluded if they underwent neoadjuvant chemoradiotherapy before surgery, if they underwent chemotherapy or other palliative treatment, if they did not receive any treatment in our institute, if they had histopathologically proven stage T3–T4 lesions or T2 lesions with tumor invasion to the outer longitudinal layer of muscularis propria, or if they had an affected margin treated with local excision with unclear tumoral invasion depth (Fig 1). In consideration of the fact that stage T2 lesions that infiltrated the outer longitudinal layer of the muscularis propria are relatively easily differentiated from stage T1 lesions, only early-stage T2 lesions that infiltrated the inner circular layer were included in this study.

MRI Acquisition

MRI examinations were performed with a 3.0-T system (Discovery MR750; GE Healthcare, Waukesha, Wis) with a phased-array surface coil. In our institution, bowel preparation included glycerin enema, administration of 10 mg of raceanisodamine hydrochloride (except in patients with contraindications), and 50–60 mL US gel for distention before MRI examinations.

Oblique axial, sagittal, and coronal non–fat-saturated high-spatial-resolution T2-weighted images were obtained orthogonal or parallel to the long axis of the tumor. Axial T1-weighted imaging, fat-saturated T2-weighted imaging, and diffusion-weighted imaging (b values of 0 sec/m^2 and 1000 sec/m^2) covering the whole pelvis were also performed. Contrast-enhanced MRI was performed by using the three-dimensional T1-weighted gradient-echo sequence 15 seconds after intravenous administration of 0.2 mL per kilogram of body weight gadopentetate dimeglumine (Magnevist; Bayer Healthcare, Berlin, Germany) at a rate of 2.0 mL/sec. Six sets of oblique axial images were obtained, with the direction being parallel to high-resolution T2-weighted images; this was followed by acquisition of one set of sagittal and coronal images. The exact MRI protocols are summarized in Table E1 (online).

Image Analysis

Two gastrointestinal radiologists (H.M.Z., Y.L.; 21 years and 17 years of experience in rectal MRI, respectively) independently reviewed the MRI scans. The two readers were blinded to any clinical or histopathologic information and achieved a unified evaluation standard to identify the MRI parameters through discussion before the independent analysis. In total, four reading sessions were presented: two sessions for independent analysis of T2-weighted and contrast-enhanced images separated by at least 2 weeks, and two sessions to reach consensus in cases with discrepancies on qualitative parameters. The mean of quantitative parameters was applied for the following uni- and multivariable analyses. The evaluated MRI characteristics of rectal cancer included tumor location, tumor shape, SES, SMP, distance from the tumor to the anal verge, maximum tumor length, and maximum tumor circumference. These characteristics are described in Table 1 and Figures 2 and 3.

Clinical Information and Histopathologic Tumor Node Metastasis Staging

Clinical information, including age, sex, and preoperative levels of carcinoembryonic antigen and carbohydrate antigen 19–9, was evaluated. The threshold values of carcinoembryonic antigen and carbohydrate antigen 19–9 levels were based on the normal ranges used at our institution (0–5 ng/mL and 0–37 U/mL, respectively).

Surgical methods included local excision (n = 96) and total mesorectal excision (n = 335), which are detailed in Table E2 (online). The existing pathologic reports presented tumor staging according to the American Joint Committee on Cancer Tumor Node Metastasis staging system.

To further explore the possible factors that affect the diagnostic accuracy of SES, a specialized pathologist (S.M.Z.) with 21 years of experience in histopathology was invited to re-review the histopathologic samples that were potentially misdiagnosed after MRI evaluation using SES as an assessed imaging feature. The depth of tumor infiltration into the submucosa or muscularis propria was measured precisely for those samples.

Statistical Analysis

The significance of each variable was assessed with univariable analysis of stage T0–T1 (T0, Tis, and T1) and stage T2 lesions. According to the Q-Q plot, the continuous variables were compared by using the t test or Mann-Whitney U test. Categorical variables were compared by using the χ^2 test. Bonferroni corrections were used for multiple comparisons. $P < .05$ was considered to indicate a significant difference. Heat maps were generated to show the distribution of variables between stage T0–T1 and stage T2 groups. The accuracy, sensitivity, and specificity for the differentiation of stage T0–T1 tumors from stage T2 tumors by using SES or SMP were calculated and compared with the McNemar test.

Interobserver agreement was quantified by using the κ statistic for categorical variables (κ = 0–0.20, poor agreement; κ = 0.21–0.40, fair agreement; κ = 0.41–0.60, moderate agreement; κ = 0.61–0.80, good agreement; and κ = 0.81–1.00, excellent agreement) and the intraclass correlation coefficient (or ICC) for continuous variables (ICC = 0–0.49, poor agreement; ICC = 0.50–0.75, moderate agreement; ICC = 0.76–0.90, good agreement; ICC = 0.91–1.00, excellent agreement) (22).

All variables that were significant at univariable analysis ($P < .05$) were candidates for multivariable regression analysis. Backward stepwise selection was applied. The β values and 95% CIs were calculated. The multivariable model was built by using the regression equation, and the receiver operating characteristic curve was plotted to evaluate the power of the model. Statistical analyses were conducted by using R software, version 3.6.1 (*https://www.r-project.org/*).

Results

Study Participants

Among the 3716 patients, 1971 were excluded because they underwent neoadjuvant chemoradiotherapy before surgery (n = 1473), received chemotherapy or other palliative treatment (n = 320), or did not receive any treatment in our institute (n = 178) (Fig 1). Subsequently, a total of 1745 patients who had rectal adenoma or adenocarcinoma and underwent primary resection were included. Among these patients, 1314 were excluded for presence of histopathologically proven T3–T4 lesions (n = 993), presence of T2 lesions with tumor invasion to the outer longitudinal layer of the muscularis propria (n = 223) or lack of specific indication of involvement of the layer of muscularis propria (n = 56), absence of contrast-enhanced MRI scans (n = 38), and insufficient image quality (n = 4). The final study population consisted of 431 patients (mean age ± standard deviation, 60 years ± 10; age range, 35–84 years; 261 men) (Table 2).

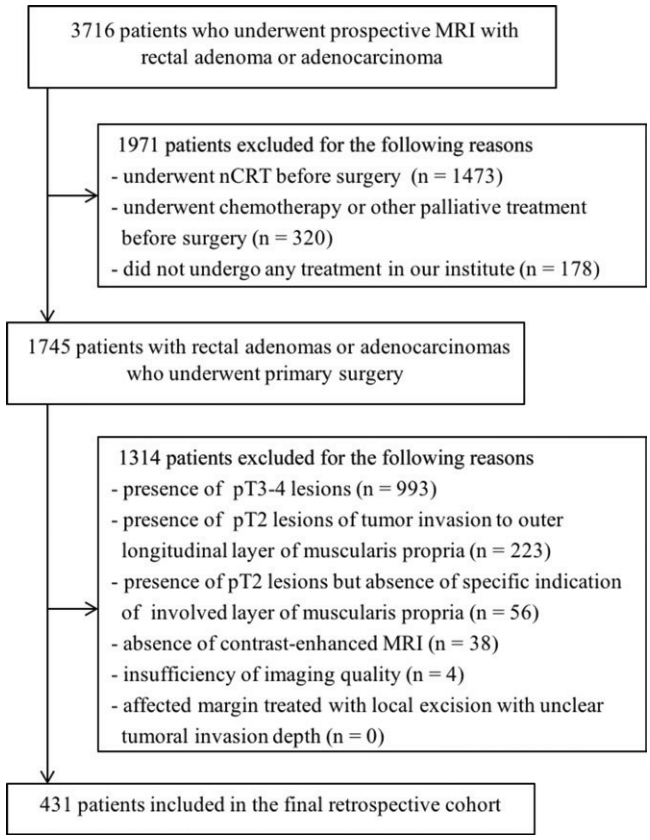

Figure 1: Flowchart shows study inclusion and exclusion criteria. nCRT = neoadjuvant chemoradiotherapy.

Among the 431 patients, 21 had T0 lesions (adenoma with or without low-grade intraepithelial neoplasia), 83 had Tis lesions (carcinoma in situ), 145 had T1 lesions (tumor invading the submucosa), and 182 had T2 lesions (tumor invading the inner circular layer of the muscularis propria only). The 431 patients were divided into two groups: a stage T0–T1 (T0, Tis, T1) group and a stage T2 group. There were 249 patients (mean age, 60 years ± 10 [standard deviation]; age range, 35–82 years; 144 men) in the T0–T1 group and 182 (mean age, 60 years ± 10; age range, 35–84 years; 117 men) in the T2 group (Fig 1).

Clinical and MRI Characteristics Associated with T0–T1 and T2 Lesions

Patients' clinical and MRI findings are described in Table 2. The distribution of age, sex, preoperative carcinoembryonic antigen level, and preoperative carbohydrate antigen 19–9 level did not differ between the T0–T1 group and the T2 group (P = .99, P = .18, P = .50, and P = .05, respectively).

Among the 249 patients with T0–T1 lesions, 209 (84%) had an uninterrupted SES between the rectal tumor and the muscular layer at contrast-enhanced T1-weighted imaging (Fig 4, *A–C*). On the basis of the tumor growth patterns, four types of SES contours were found (Fig 2). In the T2 group, 15 of 182

Table 1: MRI-based Evaluation of Tumor Characteristics

Characteristic	Evaluation or Measurement	Classification
Tumor location	Judged by oblique axial T2-weighted images according to position of tumoral main body; rectal wall is divided into four parts along two orthogonal lines that pass through perceived center of lumen	Anterior, posterior, left, and right side
Tumor shape	Categorized according to tumor structure in T2-weighted images	Pedunculated polypoidal (pedunculated and protruding into the lumen), sessile polypoidal (sessile and protruding into lumen), carpetlike (flat surface with villous feature), and focal wall thickening
Submucosal enhancing stripe	Oblique axial, sagittal, and coronal contrast material–enhanced T1-weighted sequences were used for assessment; identical results based on at least two sequences were recorded	Presence: uninterrupted enhancing stripe between rectal tumor and muscular layer Absence: disappeared or interrupted enhancing stripe
Status of muscularis propria	Assessed with T2-weighted images, with particular attention to inner border of muscularis propria	Regular, irregular
Distance from tumor to anal verge	Distance of inferior border of tumor to anal verge on sagittal T2-weighted images	…
Maximum tumor length	Maximum tumor length on sagittal T2-weighted images	…
Maximum tumor circumference	Maximum tumor circumference via oblique axial T2-weighted images	…

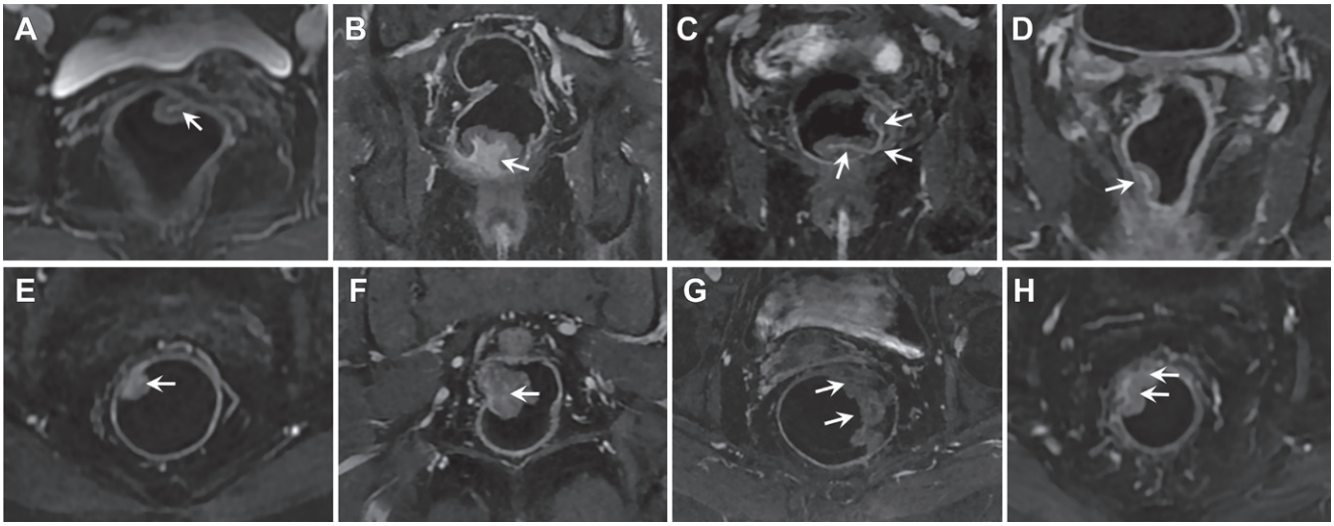

Figure 2: Contrast material–enhanced T1-weighted MRI scans show submucosal enhancing stripe (SES) evaluation criteria and examples. *A–D,* Presence of SES as an uninterrupted enhancing stripe between the rectal tumor and the muscular layer with varied contours based on the tumor growth pattern (arrows). *E–H,* Absence of SES (arrows). In, *A, E,* the tumor growth pattern is pedunculated polypoidal; in, *B, F,* the tumor growth pattern is sessile polypoidal; in, *C, G,* the tumor growth pattern is carpetlike; and in, *D, H,* the tumor growth pattern is focal rectal wall thickening.

(8.2%) lesions had an SES, whereas up to 92% (167 of 182) of the T2 lesions did not ($P < .001$) (Fig 4, *D–F*). According to the pathologist's review, of the 40 T0–T1 tumors without SES, nine were stage Tis tumors and 31 were stage T1 tumors. Twenty-six of the 31 (84%) T1 tumors showed tumor invasion to the deep third of the submucosa, and 11 of 15 (73%) T2 tumors with SES had only focal tumor invasion to the superficial muscularis propria.

Furthermore, 63% (157 of 249) of the patients with T0–T1 lesions showed regular muscularis propria at T2-weighted imaging, but 73% (133 of 182) of the patients with stage T2 lesions had an irregular or even interrupted proper muscle layer ($P < .001$).

Seventy-seven patients with T0–T1 lesions overstaged with SMP were accurately identified according to the SES. The diagnostic accuracy, sensitivity, and specificity for SES were 87% (95% CI: 84, 90; 376 of 431), 84% (95% CI: 79, 88; 209 of 249), and 92% (95% CI: 87, 95; 167 of 182), respectively. The diagnostic accuracy, sensitivity, and specificity for SMP were 67% (95% CI: 63, 72; 290 of 431), 63% (95% CI: 57, 69; 157

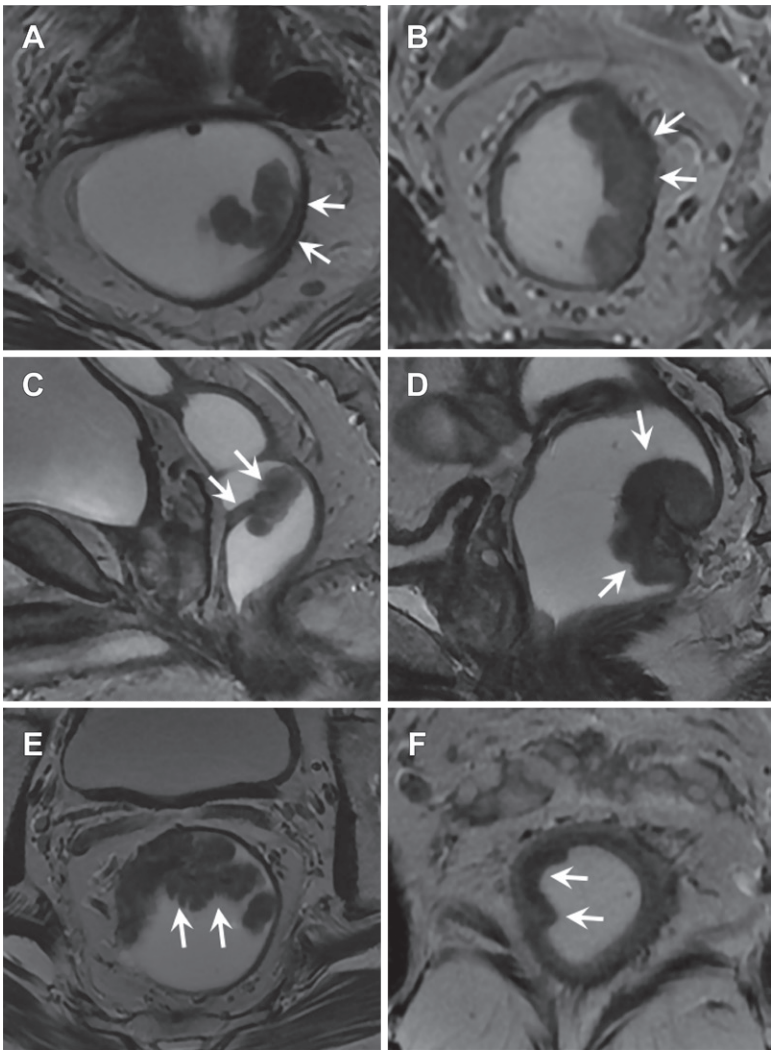

Figure 3: T2-weighted MRI scans show, *A, B,* status of muscularis propria (arrows) and, *C–F,* tumor shapes (arrows). Examples are shown for, *A,* regular and, *B,* irregular muscularis propria, as well as, *C,* pedunculated polypoidal, *D,* sessile polypoidal, *E,* carpetlike, and, *F,* focal rectal wall thickening.

of 249), and 73% (95% CI: 66, 79; 133 of 182), respectively (all $P < .001$ for comparisons with SES), in the differentiation of stage T0–T1 tumors from stage T2 tumors.

Up to 90% (65 of 72) of the pedunculated polypoidal tumors and 88% (43 of 49) of carpetlike tumors were seen in the T0–T1 group, and 65% (138 of 211) of tumors with focal rectal wall thickness belonged to the T2 group ($P < .001$). Tumor location did not differ between the T0–T1 and T2 groups ($P = .69$).

Maximum tumor length and maximum tumor circumference of T2 tumors were larger than those of T0–T1 tumors (median, 2.1 cm [interquartile range or IQR, 1.2] vs 1.4 cm [IQR, 1.5] for maximum tumor length [$P < .001$]) (median, 2.6 cm [IQR, 1.2] vs 1.7 cm [IQR, 1.7] for maximum tumor circumference [$P < .001$]). No association was found in the distance from the tumor to the anal verge between stage T0–T1 and T2 tumors (median, 5.7 cm [IQR, 4.6] vs 5.9 cm [IQR, 4.0]; $P = .91$). A heat map (Fig 5) shows the distribution of all the variables between T0–T1 and T2 groups; tumor shape, SES, SMP, maximum tumor length, and maximum tumor circumference showed different distributions between the two groups.

Interobserver Agreement for MRI Findings

Interobserver agreement for SMP was moderate ($\kappa = 0.54$; 95% CI: 0.46, 0.62), and the other predictors showed good to excellent agreement, with κ values ranging from 0.78 (95% CI: 0.73, 0.83) to 0.93 (95% CI: 0.90, 0.96) and intraclass correlation coefficients ranging from 0.97 (95% CI: 0.96, 0.98) to 0.99 (95% CI: 0.98, 0.99). Details of interobserver agreements are provided in Table 3.

Multivariable Logistic Regression Analysis

Multivariable analysis showed that SES ($P < .001$), SMP ($P < .001$), and tumor shape ($P = .03$) (Table 4) were independent factors that enabled differentiation of stage T0–T1 tumors from stage T2 tumors. Lesions with SES ($\beta = 3.9$; 95% CI: 3.1, 4.7), regular SMP ($\beta = 1.3$; 95% CI: 0.7, 1.9), carpetlike shape (β relative to focal wall thickening = 1.6; 95% CI: 0.5, 2.8), or a combination thereof had greater likelihood to be stage T0–T1 tumors than did other lesions. The multivariable model showed diagnostic ability, with an area under the receiver operating characteristic curve of 0.92 (95% CI: 0.90, 0.95) (Fig 6).

Discussion

Precisely distinguishing T0–T1 from T2 rectal tumors is essential for selecting appropriate treatment. We aimed to evaluate the ability of a submucosal enhancing stripe (SES) at contrast-enhanced MRI to differentiate stage T0–T1 lesions from stage T2 lesions. In our study, 84% (209 of 249) of T0–T1 lesions had SES compared with only 8.2% (15 of 182) of T2 lesions ($P < .001$). The SES was superior to the status of muscularis propria (SMP) in the differentiation of stage T0–T1 lesions from T2 lesions, with a diagnostic accuracy of 87% (376 of 431) versus 67% (290 of 431) ($P < .001$).

The submucosa, located between the muscularis mucosa and the muscularis propria, is a loose connective tissue layer that contains abundant blood vessels (23). After injection of contrast media, it highlighted a continuous and integrated enhancing stripe at T1-weighted imaging. Theoretically, the presence of SES in patients with a rectal tumor meant that the tumor did not penetrate through the submucosa, independent of whether the tumor had invaded it or not, a feature that was helpful in the differentiation of stage T0–T1 from stage T2 rectal tumors. We also found that 77 T0–T1 lesions that were overstaged by using the parameter of SMP at T2-weighted imaging were accurately identified with use of SES at contrast-enhanced T1-weighted imaging. Thus, although contrast-enhanced T1-weighted imaging is not routinely recommended

Table 2: Clinical and MRI Characteristics of Patients with Stage T0–T1 or Stage T2 Rectal Lesions

Characteristic	Total (*n* = 431)	Stage T0–T1 (*n* = 249)	Stage T2 (*n* = 182)	*P* Value
Age (y)*	60 ± 10	60 ± 10	60 ± 10	.99
Sex				.18
Male	261 (61)	144 (58)	117 (64)	...
Female	170 (39)	105 (42)	65 (36)	...
CEA level				.50
≤5 ng/mL	326 (76)	189 (76)	137 (75)	...
>5 ng/mL	51 (12)	27 (11)	24 (13)	...
Missing	54 (13)	33 (13)	21 (12)	...
CA19–9 level				.05
≤37 U/mL	359 (83)	201 (81)	158 (87)	...
>37 U/mL	16 (3.7)	13 (5.2)	3 (1.6)	...
Missing	56 (13)	35 (14)	21 (12)	...
Tumor location				.69
Anterior	127 (30)	68 (27)	59 (32)	...
Posterior	105 (24)	62 (25)	43 (24)	...
Left	94 (22)	55 (22)	39 (21)	...
Right	105 (24)	64 (26)	41 (23)	...
Tumor shape				<.001
Pedunculated polypoidal	72 (17)	65 (26)	7 (3.8)	...
Sessile polypoidal	99 (23)	68 (27)	31 (17)	...
Carpetlike	49 (11)	43 (17)	6 (3.3)	...
Focal wall thickening	211 (49)	73 (29)	138 (76)	...
SES				<.001
Present	224 (52)	209 (84)	15 (8.2)	...
Absent	207 (48)	40 (16)	167 (92)	...
SMP				<.001
Regular	206 (48)	157 (63)	49 (27)	...
Irregular	225 (52)	92 (37)	133 (73)	...
Median DTA (cm)†	5.9 (4.4)	5.7 (4.6)	5.9 (4.0)	.91
Median MTL (cm)†	1.8 (1.5)	1.4 (1.5)	2.1 (1.2)	<.001
Median MTC (cm)†	2.1 (1.6)	1.7 (1.7)	2.6 (1.2)	<.001

Note.—Unless otherwise indicated, data are numbers of patients, with percentages in parentheses. CA19–9 = carbohydrate antigen 19–9, CEA = carcinoembryonic antigen, DTA = distance from the tumor to the anal verge, MTC = maximum tumor circumference, MTL = maximum tumor length, SES = submucosal enhancing stripe, SMP = status of muscularis propria.

* Data are mean ± standard deviation.

† Data in parentheses are the interquartile range.

for most rectal MRI examinations, our results suggest that it can be recommended in patients suspected of having intramural rectal cancer at T2-weighted imaging for further differentiation of T0–T1 tumors from T2 tumors.

Although far from satisfactory, the diagnostic ability of SMP in this study was much better than what has been reported before (11,19,20). This was probably because of the improved image quality with updated and improved MRI field strength and coil design compared with the equipment used 10 years ago. However, the interobserver agreement for SMP was only moderate, which may limit its clinical application. Pedunculated polypoidal and carpetlike tumors were more frequently found in stage T0–T1 tumors but were seldom seen in stage T2 tumors in the current study. We speculated that the stalk of the pedunculated tumor would be damaged from tumor invasion to the muscularis propria; the carpetlike tumors would lack primary villous features if accompanied by extensively malignant transformation and deeper invasion.

The multivariable model that incorporated SES, SMP, and tumor shape enabled successful differentiation of stage T0–T1 tumors from stage T2 tumors with an area under the curve of 0.92. Except for SMP with moderate interobserver agreement, the interobserver agreements were good to excellent for the other predictors. The defined evaluation methods in the study are reproducible, and in a collaborative way these tested features can be used to distinguish stage T0–T1 tumors from stage T2 tumors very well.

It is well known that the malignancy potential of rectal adenomas increases with an increase in size (24,25); however, there are no reports focused on the association of tumor size with the depth of tumor invasion. In our study, tumor size, which includes the maximum tumor length and maximum

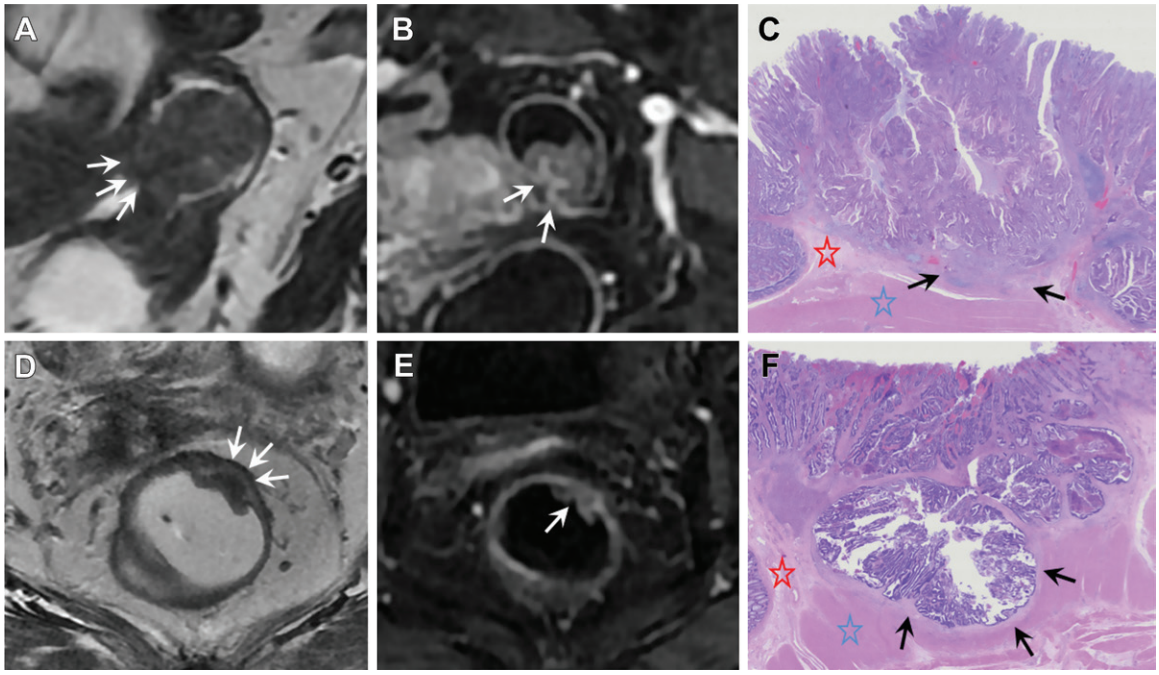

Figure 4: MRI scans in patients with rectal cancer. *A–C*, Images in a 74-year-old woman with stage T1 rectal cancer. *A*, T2-weighted image shows a rectal tumor with sessile polypoidal shape and irregular muscularis propria. *B*, Contrast material–enhanced T1-weighted image shows a tumor with a submucosal enhancing stripe (SES) (arrows). *C*, Photomicrograph shows the tumor invades the submucosa (arrow), with a normal muscularis propria (red ☆ = submucosa; blue ☆ = muscularis propria). (Hematoxylin-eosin stain; original magnification, ×20.) *D–F*, Images in a 67-year-old man with early-stage T2 rectal cancer. *D*, T2-weighted image shows a rectal tumor with focal rectal wall thickening and regular muscularis propria. *E*, Contrast-enhanced T1-weighted image shows a tumor without SES (arrows). *F*, Photomicrograph shows the tumor invades the submucosa into the inner circular layer of the muscularis propria (black arrow) (red ☆ = submucosa; blue ☆ = muscularis propria). (Hematoxylin-eosin stain; original magnification, ×50.)

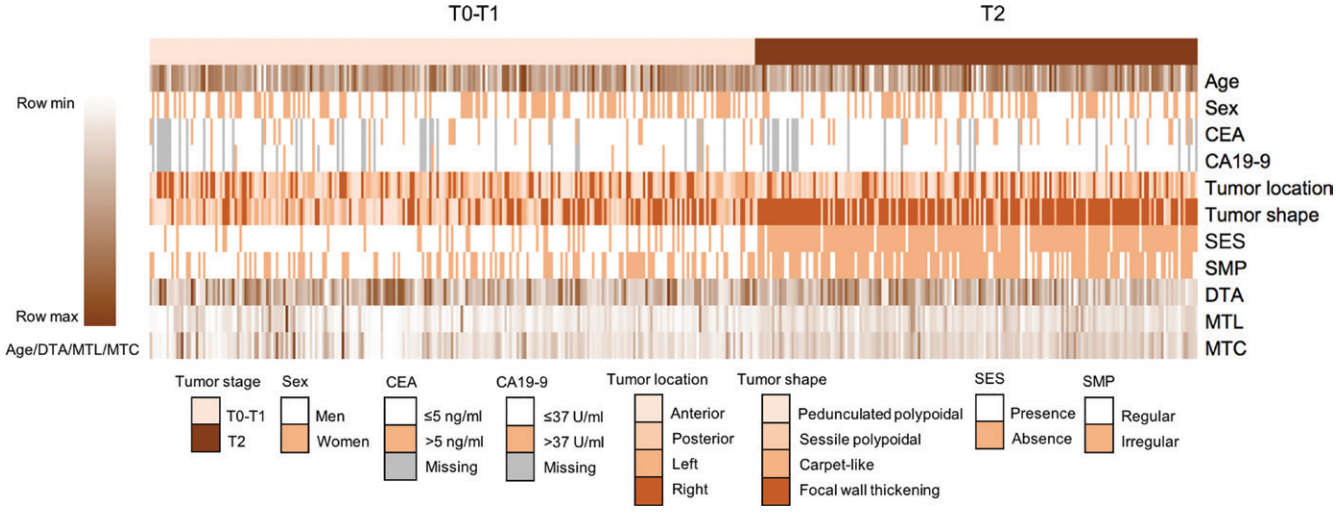

Figure 5: Heat map shows the distribution of clinical and MRI features between stage T0–T1 and stage T2 groups. Each row in the heat map corresponds to a unique feature, color coded as detailed in the legends on the left and below the heat map. Each column corresponds to one patient. Tumor shape, submucosal enhancing stripe (SES), status of muscularis propria (SMP), maximum tumor length (MTL), and maximum tumor circumference (MTC) showed different distribution between T0–T1 and T2 groups. CA19–9 = carbohydrate antigen 19–9, CEA = carcinoembryonic antigen, DTA = distance from the tumor to the anal verge.

tumor circumference, was a significant factor in the differentiation of stage T0–T1 lesions from stage T2 lesions according to univariable analysis; however, it lost its predictive potential after multivariable analysis. Measurement of maximum tumor length and maximum tumor circumference may be affected by different tumor shapes. For example, carpetlike tumors usually show relatively large maximum tumor length or maximum tumor circumference but with slight tumor invasion. Tumor thickness was not evaluated in this study because it is largely influenced by the tumor shape.

The study had several limitations. First, it was a retrospective study with inherent selection bias. Second, stage T0, Tis, and T1

Table 3: Interobserver Agreement between Two Radiologists for MRI Findings

Variable	Interobserver Agreement*
Tumor location	0.93 (0.90, 0.96)
Tumor shape	0.78 (0.73, 0.83)
Submucosal enhancing stripe	0.86 (0.81, 0.90)
Status of muscularis propria	0.54 (0.46, 0.62)
Distance from tumor to anal verge	0.97 (0.96, 0.98)
Maximum tumor length	0.99 (0.98, 0.99)
Maximum tumor circumference	0.99 (0.98, 0.99)

Note.—Data in parentheses are 95% CIs.

* Quantified by using κ statistic for categorical variables and intraclass correlation coefficient for continuous variables.

Table 4: Multivariable Analysis of Variables Associated with Stage T0–T1 Rectal Lesions

Variable	β Value	*P* Value
Submucosal enhancing stripe		<.001
Present	3.9 (3.1, 4.7)	
Absent	…	
Status of muscularis propria		<.001
Regular	1.3 (0.7, 1.9)	
Irregular	…	
Tumor shape		.03
Pedunculated polypoidal	0.4 (−0.8, 1.7)	.50
Sessile polypoidal	−0.2 (−1.1, 0.7)	.71
Carpet-like	1.6 (0.5, 2.8)	.01
Focal wall thickening	…	

Note.—Data in parentheses are 95% CIs. Number of stage T0–T1 rectal lesions, 249; number of all lesions, 431. The reference categories for each variable are as follows: submucosal enhancing stripe, absence; regular status of muscularis propria, irregular; pedunculated polypoidal, focal wall thickening; sessile polypoidal, focal wall thickening; carpetlike, focal wall thickening.

tumors were categorized as one group. The study focused on the differentiation of T1 or lower stage tumors from stage T2 tumors to select appropriate patients who can undergo minimally invasive surgery. Initially, we also tried to test whether the distance from the inner border of the tumor to the tip end of SES can help distinguish stage Tis tumors from stage T1 tumors or can help predict the submucosal invasion depth but failed because that measurement was impeded by many factors. Third, to strictly evaluate imaging features for the differentiation of stage T0–T1 tumors from T2 tumors, only early T2 tumors that infiltrated the inner muscular layer were included in the study; therefore, the number of T2 tumors was relatively smaller than the number of T0–T1 tumors. However, we believe that the results obtained by strictly selecting patients will be more reliable for supporting the treatment strategy. Fourth, we did not perform validation on an external cohort, and our results should be externally validated.

In conclusion, this study shows that submucosal enhancing stripe (SES) status in contrast-enhanced MRI, along with status of muscularis propria and tumor shape, can serve as an independent predictor in the differentiation of stage T1 or lower rectal tumors from stage T2 tumors. In addition, SES is superior to status of muscularis propria in terms of reliability and reproducibility. Performance of rectal MRI with contrast enhancement may be beneficial in patients with early stage tumors for determining appropriate care.

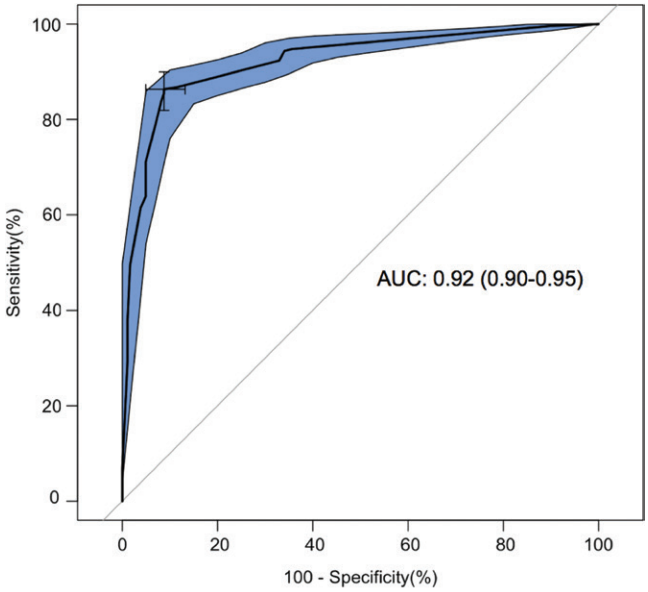

Figure 6: Receiver operating characteristic (ROC) curve analysis of multivariable models for differentiating stage T0–T1 from stage T2 rectal tumors. The blue area is the 95% CI of the ROC curve. Submucosal enhancing stripe (SES), status of muscularis propria (SMP), and tumor shape were included in the multivariable model, and the area under the ROC curve (AUC) is 0.92 (95% CI: 0.90, 0.95).

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