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RESEARCH ARTICLE

Application value of simultaneous multislice readout-segmented echo-planar imaging for diffusion-weighted MRI in differentiation of rectal cancer grade

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Abstract

Objective To analyze the association of apparent diffusion coefficient (ADC) values measured by readout-segmented echo-planar imaging (rs-EPI) using different simultaneous multislice (SMS) acceleration factors and the differentiation of rectal cancer grade.

Materials and methods Patients with non-mucinous rectal adenocarcinoma diagnosed by biopsy (endoscope-guided biopsy or surgical resection) were retrospectively collected, and each patient underwent an MRI examination. ADC values of rs-EPI, 2 × SMS rs-EPI, and 3 × SMS rs-EPI were recorded as ADC_1, ADC_2, and ADC_3, respectively.

Results The scanning time of 2 × SMS rs-EPI was 60 s, 56.2% shorter than 137 s of rs-EPI sequence, while that of 3 × SMS rs-EPI was 51 s, 72.8% less than that of rs-EPI time. The ADC value of the three groups dropped with the decrease in cancer grade ($p < 0.05$). The AUC values of ADC_1, ADC_2, and ADC_3 in predicting highly differentiated rectal cancer were 0.74, 0.729, and 0.687, respectively. The difference in AUC values between ADC_1 and ADC_2 was not statistically significant ($p = 0.889$).

Discussion SMS technology with an acceleration factor of 2 could be applied clinically to evaluate the pathological differentiation of rectal cancer grade.

Keywords Rectum · Readout-segmented echo-planar imaging · Simultaneous multislice · Apparent diffusion coefficient · Differentiation grade

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Introduction

Colorectal cancer is among the most common malignant neoplasms and the tenth most deadly cancer worldwide. Among all colorectal cancer, 30–35% arise in the rectum [1]. The tumor-node-metastasis (TNM) staging system is the most common method to predict clinical outcomes and guide therapeutic management in rectal cancer. Moreover, mesenteric fascia, histopathological grade, and vascular invasion are adjunctive prognosticators for further stratification of colorectal cancer patients [2]. However, it remains debatable whether conventional histologic differentiation grading is less suited for resected rectal cancer following neoadjuvant chemoradiation [2]. Therefore, a non-invasive and accurate assessment of rectal cancer grading is of great clinical significance for guiding subsequent clinical treatment.

Diffusion-weighted imaging (DWI) is a non-invasive MR imaging tool based on signal contrast generation and differences in Brownian motion that can reflect biological activity [3] and can be used to evaluate the molecular function and micro-architecture of the human body [4]. The apparent diffusion coefficient (ADC) from DWI provides biological implications for cell density and can identify tumor progression [5]. However, the application of traditional DWI sequences based on single-shot echo-planar imaging (ss-EPI) is limited by factors including low resolution, geometric distortion, and sensitivity to artifacts [6]. Compared with ss-EPI, the K-space acquisition of readout-segmented Echo-planar imaging (rs-EPI) can improve the imaging quality of DWI in various organs by reducing geometric distortion, providing shorter echo intervals, and improving spatial resolution [7]. Yet, its application is limited by the long scanning time.

Multi-layer data can be obtained by simultaneous multislice (SIMULTANEOUS multislice/SMS) and can significantly shorten the image acquisition time [8]. Furthermore, several recent studies have shown that ADC values based on ss-EPI and rs-EPI can be used to evaluate preoperative and prognostic factors of different cancers, including rectal cancer [9–11]. Moreover, rs-EPI technology combined with SMS has been successfully applied to evaluate the image quality of nasopharyngeal carcinoma, breast and parotid gland, and pancreas [12–15]. However, no studies have explored the relationships between ADC values measured on rs-EPI combined with SMS and rectal cancer grade differentiation. Also, the impact of rs-EPI combined with different SMS acceleration factors on the ADC values of rectal cancer is still unclear.

In this study, we analyzed the association of ADC values measured by rs-EPI using different SMS acceleration factors with the pathological differentiation of rectal cancer grade.

Materials and methods

Ethics statement

This retrospective study was approved by the Institutional Review Board. The need for written informed consent was waived by the institutional review board due to the retrospective design of the study.

Study population

Patients with non-mucinous rectum adenocarcinoma diagnosed by biopsy between December 2021 and July 2022 were included in the study. The inclusion criteria were: (1) patients with biopsy-proven rectal cancer either after endoscopic-guided biopsy or surgical resection; (2) patients with complete MRI images; (3) those who did not receive neoadjuvant radiotherapy at the time of the MRI scan. The exclusion criteria were: patients who had rectal surgery or radiochemotherapy before the examination; with poor image quality; the tumor not visible on the MRI image; unresectable or metastatic diseases; the existence of mucinous cystadenoma.

Imaging protocol

A 3 T scanner (MAGNETOM Vida, Siemens Healthiness) and 18 channel body array coils were used for MRI. Creatine-50 min was used to clean the intestinal tracts before the examination. In addition, patients were given 20 mg of scopolamine butyl bromide (Bus Copan, Boehringer Ingelheim) intramuscularly 30 min before MRI to reduce bowel motion. No rectal dilation was seen prior to the MRI examination. Conventional MRI plain scan (including sagittal, axial, and coronal T2-weighted imaging) and three rs-EPI sequences, including rs-EPI and SMS rs-EPI sequence with an acceleration factor of 2 (2 × SMS rs-EPI), and SMS rs-EPI sequence with an acceleration factor of 3 (3 × SMS rs-EPI) were all in free respiration scanning mode, and the scanning direction was perpendicular to the diseased bowel. The parameters are shown in Table 1. The conventional MR techniques for rectal cancer included routine standardized sagittal T2 and axial T1 fast spin echo (FSE) sequences together with high-resolution axial and coronal T2 FSE sequences: an axial T1 FSE sequence [repetition time/echo time (TR/TE), 500/11 ms; section thickness, 5 mm; gap, 1 mm; matrix, 320 × 224; FOV, 380 × 380 mm^2]; an axial T2 FSE sequence (TR/TE, 4050/85 ms; section thickness, 5 mm; gap, 1 mm; matrix, 320 × 324; FOV, 380 × 380 mm^2); a sagittal T2 sequence (TR/TE, 5310/113 ms; section thickness, 3 mm; gap, 0 mm; matrix, 320 × 320; FOV, 250 × 250 mm^2); oblique high-resolution axial and coronal

Table 1 Scanning parameters of three EPI sequences

Parameters	rs-EPI	2×SMS rs-EPI	3×SMS rs-EPI
b value (s/mm^2)	0.1000	0.1000	0.1000
Fat suppression	SPAIR	SPAIR	SPAIR
TR (ms)	5000	2270	1800
TE (ms)	51	52	54
Inversion time	210	210	210
FOV (mm)	216×216	216×216	216×216
Matrix	128×128	128×128	128×128
Voxel (mm^3)	1.7×1.7×4.5	1.7×1.7×4.5	1.7×1.7×4.5
Slice thickness (mm)	4.5	4.5	4.5
Interlayer spacing (mm)	0.45	0.45	0.45
Number of slices	24	24	24
Slice acceleration factor		2	3
Bandwidth (Hz/Px)	998	998	998
Acquisition time (s)	137	60	51

T2 sequences (TR/TE, 5629/85 ms; section thickness, 2 mm; gap, 0 mm; matrix, 448×314; FOV, 200×200 mm^2). The axial imaging was perpendicular to the long axis of the rectal tumor, as identified by sagittal T2 imaging.

All the *b* values of the DWI sequence were 0 and 1000 s/mm^2. The device automatically created ADC figures.

Image analysis

The MRI images were independently reviewed by two radiologists (Y. T. Wang and G. H. Yan, with 10 and 15 years of experience in reading Rectal MRI, respectively) who were blind to clinicopathological results but were aware that patients were diagnosed with rectal cancer. For intratumoral ADC measurements, regions of interest (ROI$_s$) included the largest tumor area, avoiding cystic, necrotic, and visible vascular structures on T2-weighted images. Two radiologists manually drew ROI using $b=0$ s/mm^2 of rs-EPI or SMS rs-EPI independently and then copied the ROI to the ADC map (Fig. 1) for recording the ADC values. ADC values of RS-EPI, 2×SMS RS-EPI, and 3×SMS RS-EPI were recorded and specified as ADC$_1$, ADC$_2$, and ADC$_3$, respectively.

Statistical analysis

SPSS version 22 (IBM Corporation) and MedCalc (Version 16.8) were used for statistical analyses. A two-way mixed model was used to calculate the intraclass correlation coefficients (ICCs) with an absolute agreement for evaluating the agreement between the ADC values from the two radiologists. Eighty-three patients were randomly selected for ICC, which was classified as poor (ICC < 0.5), moderate (0.5 ≤ ICC < 0.75), good (0.75 ≤ ICC < 0.9), and excellent (ICC ≥ 0.9) [16]. The mean value of the ADC values measured by two radiologists was adopted for further study. Freidman test was conducted to compare the ADC values between various differentiation grades and between ADC groups with different differentiation grades in each group. Pairwise comparison was further performed using paired Wilcoxon signed rank-sum test for statistically significant difference ($p < 0.05$). Nonparametric Spearman rank correlation was conducted for evaluating the correlation between ADC$_1$, ADC$_2$, ADC$_3$, and differentiation grade of rectal cancer pathological tissues; *r* value from 0 to 0.25 was taken to represent little or no correlation: 0.25–0.5 indicated moderate correlation, 0.5–0.75 indicated a good correlation, and from 0.75 to 1.0 represented very good or excellent correlation [17].

The receiver-operating characteristic (ROC) curve was adopted to determine the predictive value of ADC values of different groups to differentiated rectal cancer, indicated by the area under the curve (AUC). The DeLong test was used to compare the AUC of ADC$_1$ and ADC$_2$. Optimal cutoffs for each ADC parameter were determined at points that maximized Youden's J index based on receiver-operating characteristic (ROC) curves. Youden's index was calculated by specificity + sensitivity-1 [18]. A two-sided *p* value < 0.05 represented statistical significance.

Results

Patients

Based on the clinical history and physical examination results, 203 patients with clinically suspected rectal cancer were enrolled. One hundred and twenty patients were excluded based on the exclusion criteria: (1) insufficient image quality due to gas-induced susceptibility artifacts or movement artifacts which prevented accurate measurement of the region of interest (ROI) ($n=54$); (2) tumor not visible on the MRI image ($n=15$); (3) unresectable or metastatic diseases ($n=21$); (4) the existence of mucinous cystadenoma, whose cell density was low (high ADC values) ($n=30$).

Finally, 83 patients (55 males and 28 females, 22–76 years old, with a mean age of 54.6 ± 11.9 years) who underwent MRI were included in this study. The clinicopathological features of the patients are shown in Table 2. According to the glandular and ductal morphological features, rectal cancer was classified as a moderately and or poorly differentiated tumor [3].

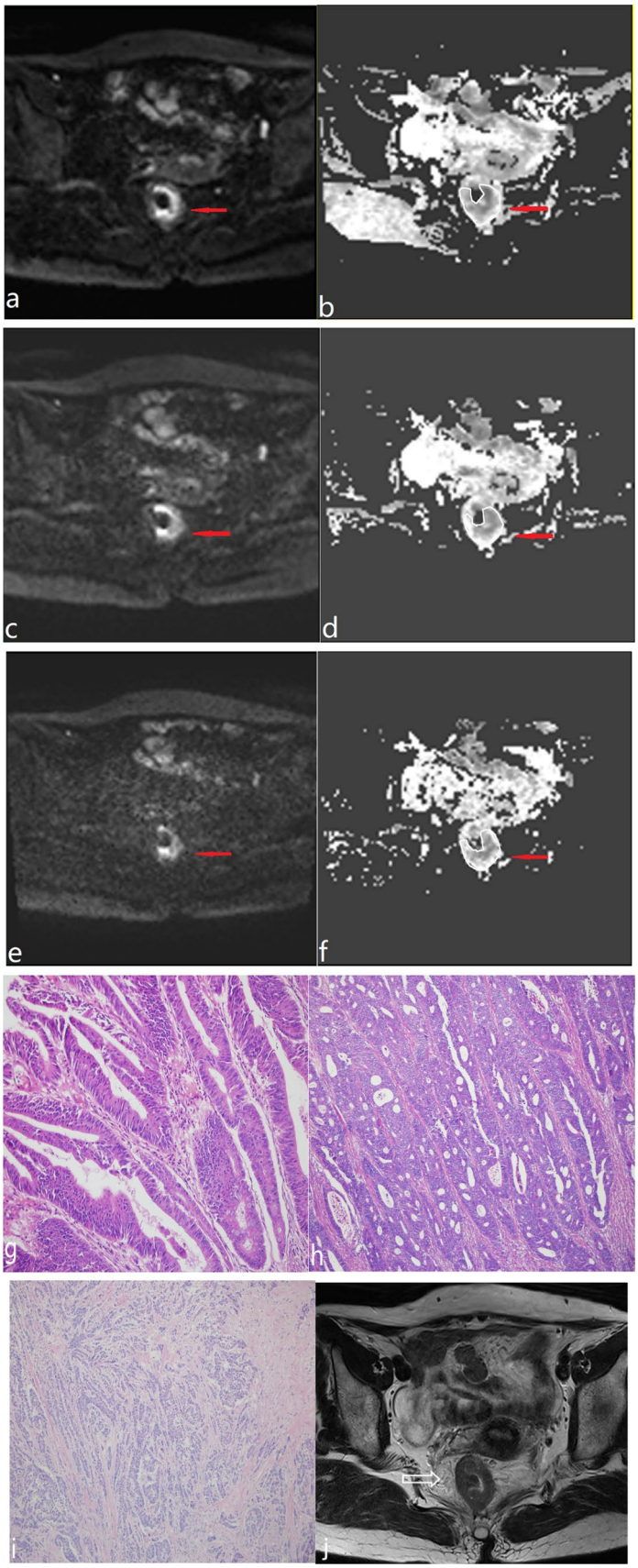

Fig. 1 Male, 53 years old, with moderately differentiated rectal cancer. **a**, **b** Conventional rs-EPI sequence with *b* value of 1000 s/mm^2 and ADC map, respectively. The ADC value was 1.16×10^{-3} mm^2/s, and the SNR was 45.36. **c**, **d** 2 × SMS rs-EPI sequence with *b* value of 1000 s/mm^2 and ADC map, respectively. The ADC value was 1.04×10^{-3} mm^2/s, and the SNR was 42.36. **e**, **f** 3 × SMS rs-EPI sequence with *b* value of 1000 s/mm^2 and ADC map, respectively. The ADC value was 1.18×10^{-3} mm^2/s, and the SNR was 40.21. **g–i** Highly (**g**), moderately (**h**), and poorly (**i**) differentiated rectal cancer, respectively. The red line points to a tumor. **j** The axial T2WI image

Table 2 Clinicopathological characteristics of the patients

Clinicopathological characteristics	*n* Percentage (%)
Gender	
Male	44 (53.01)
Female	39 (46.99)
Age (years)	58.82 (11.71)
BMI/(kg m^{-2})	22.82 (1.91)
Location of tumor	
Upper-middle segment	34 (40.96)
Lower segment	49 (59.04)
Differentiation grade	
Well	13 (15.7)
Moderate	64 (77.1)
Poor	6 (7.2)
CEA	
+	55 (66.27)
−	28 (33.73)
CA19-9	
+	40 (48.19)
−	43 (51.81)
Nerve invasion	
+	56 (67.5)
−	27 (32.5)
Vascular cancer embolus	
+	61 (73.5)
−	22 (26.5)
Cancer nodules	
+	68 (81.9)
−	15 (18.1)

Acquisition time

The scanning time of 2 × SMS rs-EPI was 60 s, 56.2% shorter than 137 s of rs-EPI sequence, while that of 3 × SMS rs-EPI was 51 s, 72.8% less than that of rs-EPI time.

Interobserver agreement of ADC parameters

Interobserver agreement was excellent for ADC_1 [intraclass correlation coefficient (ICC), 0.935; 95% CI 0.467–0.979], ADC_2 (ICC, 0.947; 95% CI 0.167–0.986), and ADC_3 (ICC, 0.946; 95% CI 0.213–0.986).

The relationship between ADC values of the three sequences and the differentiation grade of pathological tissues

The comparison of ADC value and differentiation grade of pathological tissues of rs-EPI sequence in the three groups is shown in Fig. 2 and Table 3. Among 83 patients with rectal cancer, 15.7% (13/83) were with highly differentiated rectal cancer, 77.1% (64/83) with moderately differentiated rectal cancer, and 7.2% (6/83) with poorly differentiated rectal cancer. The ADC value of the three groups dropped with the decrease in the pathological grade. ADC_1 and ADC_2 between the highly differentiated group and a moderately differentiated group showed no significant differences ($p > 0.05$); there were significant differences in ADC_2 values between high differentiation and poor differentiation, moderate differentiation and poor differentiation ($p < 0.05$), while differences among various differentiated groups in ADC_3 were statistically significant (all $p < 0.05$).

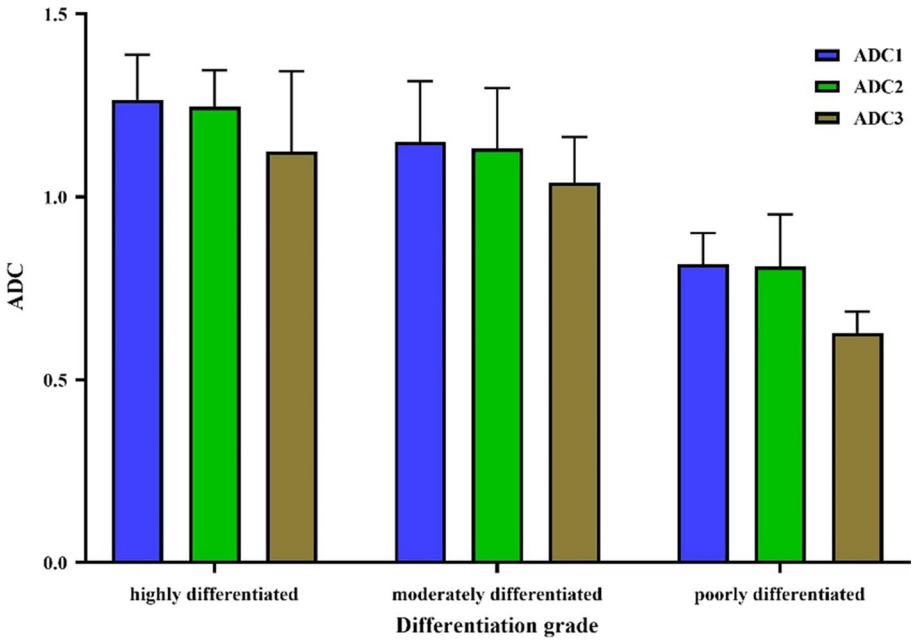

Fig. 2 Histogram show the ADC values of the three groups of sequences at different degrees of differentiation. ADC values of rs-EPI, 2 × SMS rs-EPI, and 3 × SMS rs-EPI were recorded as ADC_1, ADC_2, and ADC_3, respectively

In the highly differentiated rectal cancer group, differences among ADC_1, ADC_2, and ADC_3 groups were not statistically significant ($p=0.219$).

In the moderately differentiated rectal cancer group, the difference between the three groups was significant ($p<0.001$). Pairwise comparison showed no significant difference between ADC_1 and ADC_2 ($p=0.109$) but significant differences between ADC_1 and ADC_3 ($p<0.001$) and between ADC_2 and ADC_3 ($p<0.001$).

In the poorly differentiated rectal cancer group, the differences among ADC_1, ADC_2, and ADC_3 groups were statistically significant ($p=0.009$). Pairwise comparison showed no statistically significant difference between ADC_1 and ADC_2 ($p=0.752$) but a significant difference between ADC_1 and ADC_3 ($p=0.028$) and between ADC_2 and ADC_3 ($p=0.028$).

According to correlation analysis (Table 4), ADC_1, ADC_2, and ADC_3 were positively correlated with the differentiated histological degree of rectal cancer ($p<0.05$), among which ADC_1 had the highest correlation, followed by ADC_2.

Diagnostic efficiency on ADC value of rs-EPI sequence in highly differentiated rectal cancer in these three groups

Table 5 shows that the AUC values of ADC_1, ADC_2, and ADC_3 in predicting highly differentiated rectal cancer were 0.74, 0.729, and 0.687, respectively, with respective sensibilities of 84.6%, 92.3%, and 69.2%, respectively; specificities of 55.7%, 51.4%, and 88.6%, respectively; thresholds of 1.185×10^{-3} mm^2/s, 1.135×10^{-3} mm^2/s, and 1.155×10^{-3} mm^2/s, respectively. The ROC curve is shown in Fig. 3. The AUC values of ADC1 and ADC2 were not statistically different ($p=0.889$).

Discussion

Our data suggested that compared with rs-EPI, SMS technology with an acceleration factor of 2 significantly reduces the scanning time and maintains stable diagnostic performance to highly differentiated rectal cancer, and could therefore be applied to evaluate the pathological differentiation grade of rectal cancer and be further extended in clinical practice.

ADC value obtained by DWI-MR imaging can reflect the microanatomical structure information of tissues [19]. Some studies have suggested using ADC as a non-invasive marker of tumor aggressiveness. A previous study reported that lower ADC values are associated with a more aggressive tumor profile for rectal cancer, and significant correlations were found between mean ADC values and differentiation grade with peritumoral edema [20]. Yang et al. found that the mean ADC value could predict a pathologic complete response after undergoing preoperative chemoradiotherapy [21]. Therefore, DWI has been increasingly used in detecting

Table 3 The comparison of ADC value and differentiation grade of pathological tissues of rs-EPI sequence in the three groups

Differentiation grade	ADC_1 (±SD)	ADC_2 (±SD)	ADC_3 (±SD)
Highly differentiated ($n=13$)	1.27 (±0.12)	1.25 (±0.10)	1.12 (±0.22)
Moderately differentiated ($n=64$)	1.15 (±0.17)	1.13 (±0.17)	1.04 (±0.12)
Poorly differentiated ($n=6$)	0.82 (±0.09)	0.81 (±0.14)	0.63 (±0.06)
p value	0.011	0.009	0.011
Highly differentiated versus moderately differentiated tumor	0.906	0.307	0.046
Highly differentiated versus poorly differentiated tumor	0.027	0.028	0.028
Moderately differentiated versus poorly differentiated tumor	0.028	0.027	0.028

Table 4 The correlation of ADC value and differentiation grade of pathological tissues of rs-EPI sequence in the three groups

Parameters	ADC_1		ADC_2		ADC_3	
Differentiation grade	*r* value	*p* value	*r* value	*p* value	*r* value	*p* value
	0.455	<0.001	0.436	<0.001	0.419	<0.001

Table 5 Diagnostic efficiency on ADC value of rs-EPI sequence in highly differentiated rectal cancer in these three groups

Parameters	AUC	Cutoff value	Sensitivity (%)	Specificity (%)	*p* value
Well versus moderate-poor differentiation					
ADC_1 ($\times10^{-3}$ mm^2/s)	0.74 (0.632, 0.830)	1.185	0.846	0.557	0.006
ADC_2 ($\times10^{-3}$ mm^2/s)	0.729 (0.620, 0.820)	1.135	0.923	0.514	0.009
ADC_3 ($\times10^{-3}$ mm^2/s)	0.687 (0.576, 0.784)	1.155	0.692	0.886	0.033

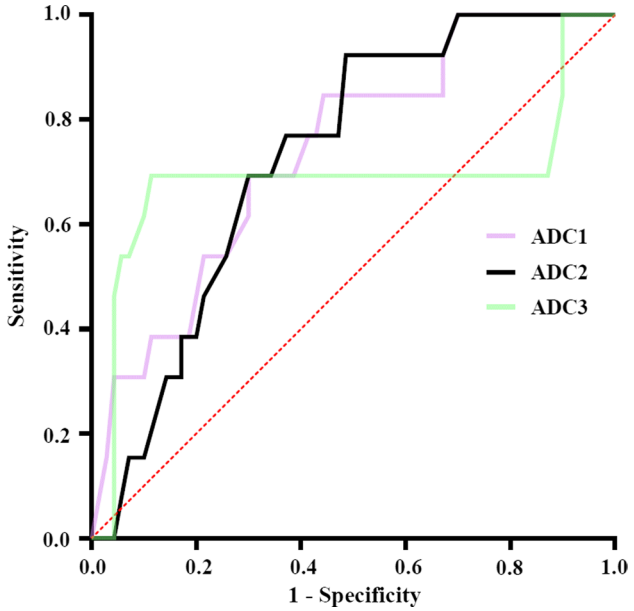

Fig. 3 Receiver operating characteristic curves of the performance of ADC_1, ADC_2, and ADC_3. ADC values of rs-EPI, 2×SMS rs-EPI, and 3×SMS rs-EPI were recorded as ADC_1, ADC_2, and ADC_3, respectively

and characterizing rectal cancer and monitoring rectal cancer after neoadjuvant chemotherapy [20]. However, it is susceptible to image blur and spatial deformation when standard DWI based on single-shot echo plane imaging is used [6].

Rs-EPI has been suggested as a good variant of EPI for high-resolution imaging, particularly when combined with parallel imaging. This is because it can shorten the echo interval, reduce the geometric distortion, and obtain better image quality and diagnostic efficiency, compared with the traditional EPI sequence. However, its ADC value has no statistical difference compared to traditional DWI [22]. In addition, it has the disadvantage of a long scanning time [7].

SMS technology is a relatively novel MRI technology that uses parallel image reconstruction, which is simultaneously excited by multiple frequency composite of pulses and multiple imaging levels [8]. Compared with conventional ss-EPI sequence, $b = 1000$ s/mm^2 images in 2×SMS ss-EPI sequence show no significant difference in overall image quality, lesion significance, and anatomical details. Also, the comparison between rectal and background tissue is sharp, and there are no obvious artifacts [23]. However, to the best of our knowledge, no study explored the relationships between the differentiation grades of rectal cancer by combining SMS technology with rs-EPI. Therefore, the acceleration factor of SMS and rs-EPI in terms of ADC values needs to be studied systematically to determine the balance between scan time minimization and image quality.

Different SMS acceleration factors by referring to the relationships between the different ADC values measured by rs-EPI and the rectal cancer grade differentiation were evaluated in this study. The differentiation of rectal cancer grade is one of the important factors affecting the prognosis [2]. With the decrease of tumor differentiation, the malignant structure becomes more complex, with more neovascularized and necrotic structures and greater heterogeneity, thus significantly restricting the movement of water molecules [24]. Our results show that the ADC values of the three sequences decreased with the decrease of differentiation, and there was statistical significance for the differences in ADC values at different levels of tissue differentiation ($p < 0.05$), which was consistent with previous research results [19, 20, 25, 26]. This resulted from the fact that with the increase of the degree of the malignant tumor, the proliferation of tumor cells significantly accelerated, and the ratio of the nucleus and the cell density per unit volume increased, leading to the decrease of the extracellular space distance and that of free diffusion of water molecules, limitation of diffusion, and in turn, lower ADC value [20]. However, there are controversial results of no significant difference between RESOLVE ADC values and different degrees of pathologic differentiation in Cui's study [3], which may be attributed to the different selected b values and a small number of cases with high and poor differentiation. In this study, the ADC images were obtained at 1000 s/mm^2, and the ADC values were measured, improving the sensitivity of DWI and effectively overcoming the influence of perfusion and the T2 shine-through effect. In addition, the accuracy of ADC values was improved [27]. There were no statistical differences between high and medium differentiation for the ADC values of the three groups, indicating that the micro-environment of cells is similar in highly and moderately differentiated tissues, and the diffusion degree of water molecules is also similar.

This study showed that when the SMS acceleration factor was 3, the ADC_3 value was significantly lower than that of ADC_1, and the difference was statistically significant ($p < 0.05$), indicating that SMS with an acceleration factor of 2 could obtain ADC values as stable and accurate as rs-EPI and that the scanning time was significantly shortened. However, when comparing moderately and poorly differentiated tissues, ADC_3 was statistically different from ADC_1 and ADC_2, which was mainly attributed to the fact that high SMS accelerators caused instability in the measurement of ADC values at high levels of cell malignancy. Hence, SMS with an acceleration factor of 3 could significantly reduce the scanning time, but caution should still be exercised in rectal applications.

In the present study, according to ROC curve analysis, ADC_1 obtained by rs-EPI had the highest diagnostic efficacy for highly differentiated rectal cancer (AUC = 0.74), the lowest diagnostic efficacy for 3×SMS rs-EPI (0.687), and the highest sensitivity for 2×SMS rs-EPI for highly differentiated rectal cancer (0.923), meanwhile, the diagnostic efficacy

of 2×SMS rs-EPI was not significantly different from rs-EPI (0.729 vs. 0.74). The cutoff of the three sequences was stable, with an average value of 1.158×10^{-3} mm^2/s. The correlation between ADC_1 and the differentiation degree of rectal cancer was the highest ($r=0.455$) and the lowest for ADC_3 ($r=0.419$), which were moderately correlated due to the heterogeneity of tumor, as different degrees of differentiation may exist within the same tumor [28]. Therefore, combining the diagnostic efficiency of differentiation grade and scanning time, it can be inferred that SMS with an acceleration factor of 2 is provided with a certain potential in studying pathological differentiation of rectal cancer.

This study has a few limitations. First, only one MR 3.0 T scanner was used instead of scanners with different field strengths, making it impossible to evaluate the impact of different field strengths on the application of SMS technology. Second, manual measurement of ROI increased the possibility of sample error, and different degrees of differentiation within the same tumor could be observed due to the heterogeneity of tumor differentiation. To this end, further studies are expected to be carried out on the correlation between different ROI measurement methods and differentiation grades. Third, moderately and poorly differentiated rectal cancer was combined for detailed research, and larger sample sizes were needed to assess histological types of rectal cancer, since there were only six poorly differentiated cases.

In conclusion, compared with rs-EPI, SMS technology with an acceleration factor of 2 significantly reduces the scanning time and can be applied to evaluate the pathological differentiation grade of rectal cancer.

Declarations

Conflict of interest All authors declare that they have no conflict of interest.

References

1. Siegel RL, Miller KD, Jemal A (2020) Cancer statistics, 2020. CA Cancer J Clin 70:7–30
2. Zhu L, Pan Z, Ma Q, Yang W, Shi H, Fu C, Yan X, Du L, Yan F, Zhang H (2017) Diffusion kurtosis imaging study of rectal adenocarcinoma associated with histopathologic prognostic factors: preliminary findings. Radiology 284:66–76
3. Tang C, Lin MB, Xu JL, Zhang LH, Zuo XM, Zhang ZS, Liu MX, Xu JM (2018) Are ADC values of readout-segmented echo-planar diffusion-weighted imaging (RESOLVE) correlated with pathological prognostic factors in rectal adenocarcinoma? World J Surg Oncol 16:138
4. Tang L, Zhou XJ (2019) Diffusion MRI of cancer: From low to high b-values. J Magn Reson Imaging 49:23–40
5. Geng Z, Zhang Y, Yin S, Lian S, He H, Li H, Xie C, Dai Y (2020) Preoperatively grading rectal cancer with the combination of intravoxel incoherent motions imaging and diffusion kurtosis imaging. Contrast Media Mol Imaging 2020:2164509
6. Porter DA, Heidemann RM (2009) High resolution diffusion-weighted imaging using readout-segmented echo-planar imaging, parallel imaging and a two-dimensional navigator-based reacquisition. Magn Reson Med 62:468–475
7. Xu XQ, Liu J, Hu H, Su GY, Zhang YD, Shi HB, Wu FY (2016) Improve the image quality of orbital 3 T diffusion-weighted magnetic resonance imaging with readout-segmented echo-planar imaging. Clin Imaging 40:793–796
8. Barth M, Breuer F, Koopmans PJ, Norris DG, Poser BA (2016) Simultaneous multislice (SMS) imaging techniques. Magn Reson Med 75:63–81
9. Boca Petresc B, Caraiani C, Popa L, Lebovici A, Feier DS, Bodale C, Buruian MM (2022) The utility of ADC first-order histogram features for the prediction of metachronous metastases in rectal cancer: a preliminary study. Biology (Basel) 11:1
10. Yuan Y, Chen XL, Li ZL, Chen GW, Liu H, Liu YS, Pang MH, Liu SY, Pu H, Li H (2022) The application of apparent diffusion coefficients derived from intratumoral and peritumoral zones for assessing pathologic prognostic factors in rectal cancer. Eur Radiol 1:1
11. Xia CC, Pu J, Zhang JG, Peng WL, Li L, Zhao F, Zhang K, Li YM, Liu KL, Meng WJ, Deng XB, Zhou XY, Li ZL (2018) Readout-segmented echo-planar diffusion-weighted MR for the evaluation of aggressive characteristics of rectal cancer. Sci Rep 8:12554
12. Song SE, Woo OH, Cho KR, Seo BK, Son YH, Grimm R, Liu W, Moon WK (2021) Simultaneous multislice readout-segmented echo planar imaging for diffusion-weighted mri in patients with invasive breast cancers. J Magn Reson Imaging 53:1108–1115
13. Tu C, Shen H, Liu D, Chen Q, Yuan X, Li X, Wang X, Liu R, Wang X, Li Q, Liu W, Zhang J (2021) Simultaneous multi-slice readout-segmentation of long variable echo-trains for accelerated diffusion-weighted imaging of nasopharyngeal carcinoma: a feasibility and optimization study. Clin Imaging 79:119–124
14. Jiang JS, Zhu LN, Wu Q, Sun Y, Liu W, Xu XQ, Wu FY (2020) Feasibility study of using simultaneous multi-slice RESOLVE diffusion weighted imaging to assess parotid gland tumors: comparison with conventional RESOLVE diffusion weighted imaging. BMC Med Imaging 20:93
15. Taron J, Martirosian P, Kuestner T, Schwenzer NF, Othman A, Weiss J, Notohamiprodjo M, Nikolaou K, Schraml C (2018) Scan time reduction in diffusion-weighted imaging of the pancreas using a simultaneous multislice technique with different acceleration factors: How fast can we go? Eur Radiol 28:1504–1511
16. Koo TK, Li MY (2016) A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 15:155–163
17. Attenberger UI, Pilz LR, Morelli JN, Hausmann D, Doyon F, Hofheinz R, Kienle P, Post S, Michaely HJ, Schoenberg SO, Dinter DJ (2014) Multi-parametric MRI of rectal cancer—Do quantitative functional MR measurements correlate with radiologic and pathologic tumor stages? Eur J Radiol 83:1036–1043
18. Youden WJ (1950) Index for rating diagnostic tests. Cancer 3:32–35
19. Cho EY, Kim SH, Yoon JH, Lee Y, Lim YJ, Kim SJ, Baek HJ, Eun CK (2013) Apparent diffusion coefficient for discriminating metastatic from non-metastatic lymph nodes in primary rectal cancer. Eur J Radiol 82:e662-668
20. Curvo-Semedo L, Lambregts DM, Maas M, Beets GL, Caseiro-Alves F, Beets-Tan RG (2012) Diffusion-weighted MRI in rectal cancer: apparent diffusion coefficient as a potential noninvasive marker of tumor aggressiveness. J Magn Reson Imaging 35:1365–1371
21. Yang L, Qiu M, Xia C, Li Z, Wang Z, Zhou X, Wu B (2019) Value of high-resolution DWI in combination with texture analysis for the evaluation of tumor response after preoperative

chemoradiotherapy for locally advanced rectal cancer. AJR Am J Roentgenol 1:1–8
22. Xia CC, Liu X, Peng WL, Li L, Zhang JG, Meng WJ, Deng XB, Zuo PL, Li ZL (2016) Readout-segmented echo-planar imaging improves the image quality of diffusion-weighted MR imaging in rectal cancer: comparison with single-shot echo-planar diffusion-weighted sequences. Eur J Radiol 85:1818–1823
23. Park JH, Seo N, Lim JS, Hahm J, Kim MJ (2020) Feasibility of simultaneous multislice acceleration technique in diffusion-weighted magnetic resonance imaging of the rectum. Korean J Radiol 21:77–87
24. White NS, McDonald C, Farid N, Kuperman J, Karow D, Schenker-Ahmed NM, Bartsch H, Rakow-Penner R, Holland D, Shabaik A, Bjørnerud A, Hope T, Hattangadi-Gluth J, Liss M, Parsons JK, Chen CC, Raman S, Margolis D, Reiter RE, Marks L, Kesari S, Mundt AJ, Kane CJ, Carter BS, Bradley WG, Dale AM (2014) Diffusion-weighted imaging in cancer: physical foundations and applications of restriction spectrum imaging. Can Res 74:4638–4652
25. Akashi M, Nakahusa Y, Yakabe T, Egashira Y, Koga Y, Sumi K, Noshiro H, Irie H, Tokunaga O, Miyazaki K (1987) (2014) Assessment of aggressiveness of rectal cancer using 3-T MRI: correlation between the apparent diffusion coefficient as a potential imaging biomarker and histologic prognostic factors. Acta Radiol (Stockholm Sweden) 55:524–531
26. Holdsworth SJ, Yeom K, Skare S, Gentles AJ, Barnes PD, Bammer R (2011) Clinical application of readout-segmented-echo-planar imaging for diffusion-weighted imaging in pediatric brain, AJNR. Am J Neuroradiol 32:1274–1279
27. Hosonuma T, Tozaki M, Ichiba N, Sakuma T, Hayashi D, Yanaga K, Fukuda K (2006) Clinical usefulness of diffusion-weighted imaging using low and high *b*-values to detect rectal cancer. Magn Reson Med Sci MRMS Off J Jpn Soc Magn Reson Med 5:173–177
28. Liu J, Li Q, Tang L, Huang Z, Lin Q (2021) Correlations of mean and mimimum apparent diffusion coefficient values with the clinicopathological features in rectal cancer. Acad Radiol 28(Suppl 1):S105–S111