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Image Quality Assessment of Reduced Field-of-View DWI in Rectal Cancer and Its Role in Preoperative T Staging

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Abstract: ***Objective:*** ***To construct reduced field-of-view diffusion-weighted imaging (rFOV DWI) based on a 3.0T MRI system and evaluate its technical advantages in rectal cancer imaging, as well as its diagnostic value for preoperative T staging, through comparative analysis of image quality with conventional field-of-view DWI (cFOV DWI).*** ***Materials and Methods:*** ***Forty-seven patients with pathologically confirmed rectal adenocarcinoma were prospectively enrolled from March 2023 to December 2024, with 30 cases selected for image quality comparison. This study was approved by the Institutional Review Board. All patients underwent preoperative MRI examinations, including both cFOV DWI and rFOV DWI. A paired study design was employed to analyze the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the two DWI sequences. Subjective image quality scoring (5-point scale) was performed using a double-blind method. Paired t-tests were used to compare objective parameters, while Wilcoxon signed-rank tests were applied for subjective scoring differences and ADC value comparisons between the two sequences. Postoperative pathological T staging served as the gold standard, and the diagnostic accuracy of rFOV DWI was evaluated using Kappa consistency analysis.*** ***Results:*** ***rFOV DWI demonstrated significantly higher objective image quality metrics compared to cFOV DWI (SNR: 139.86 ± 41.54 vs. 156.36 ± 35.94; CNR: 1.87 ± 0.43 vs. 2.24 ± 0.45, P < 0.001). Subjective image quality scores for rFOV DWI were also significantly superior (P < 0.001), indicating higher resolution, reduced distortion, and clearer lesion visualization. Preoperative T staging using rFOV DWI showed good consistency with pathological results (Kappa = 0.650, P < 0.05).*** ***Conclusion:*** ***The rFOV DWI technique significantly improves MRI image quality in rectal cancer by optimizing the scanning field of view. Its preoperative T staging demonstrates strong agreement with pathological outcomes, highlighting its critical clinical value.***

Keywords: Rectal cancer, DWI, Image quality, T staging.

1. Introduction

Colorectal cancer, as one of the major types of gastrointestinal tumors globally, accounts for over one million annual deaths, representing approximately one-third of the total colorectal cancer incidence. It has become a significant public health challenge [1, 2]. Among these, rectal cancer, due to its insidious early symptoms (often presenting as non-specific symptoms such as abdominal pain, perianal discomfort, and hematochezia) and the significant differences in treatment strategies and prognosis among patients at different stages, has become the most clinically challenging subtype of colorectal malignancy to manage. Therefore, precise preoperative assessment of rectal cancer T stage (depth of tumor invasion), N stage, and the presence of vascular or perineural invasion is of decisive importance for formulating individualized treatment plans, improving surgical outcomes, and enhancing patients' quality of life [3].

In the field of medical imaging evaluation, magnetic resonance imaging (MRI), leveraging its advantages in multiplanar imaging, excellent soft tissue contrast, and absence of ionizing radiation, has become the preferred imaging modality for precise preoperative assessment of rectal cancer. This technology not only clearly visualizes the anatomical layers of the rectal wall and the involvement of the mesorectal fascia but also provides crucial imaging evidence for neoadjuvant chemoradiotherapy decisions in locally advanced rectal cancer (T3/T4 tumors and N1/N2 lymph node metastasis status). MRI technology can provide not only morphological information about the tumor but also reflect the physiological and pathological status within living tissues non-invasively through functional magnetic resonance imaging (fMRI). However, existing research indicates that conventional MRI still has significant limitations in terms of T staging accuracy [4]. With the rapid iteration of MRI technology and innovations in multimodal fusion imaging platforms, functional magnetic resonance imaging has transcended the limitations of traditional anatomical imaging, achieving a combination of macroscopic morphology and microscopic function, becoming a research hotspot both domestically and internationally.

Diffusion-weighted imaging (DWI), based on the principle of anisotropic diffusion of water molecules, can non-invasively reflect tissue cellularity and microstructural characteristics by quantitatively detecting the degree of restriction and directionality of Brownian motion of water molecules within biological tissues [5, 6]. Its core parameter, the apparent diffusion coefficient (ADC), which corrects for the T2 shine-through effect, more objectively reflects tissue diffusion characteristics [7, 8] and is now widely used in tumor diagnosis and grading assessment. Multiple studies have confirmed that DWI-derived ADC values can predict the pathological T stage of rectal cancer non-invasively, demonstrating significant clinical value [9-11]. Currently, clinical practice primarily employs single-shot echo-planar imaging DWI (SS-EPI-DWI), but this technique is limited by low spatial resolution and significant susceptibility artifacts, leading to image distortion and deformation in areas with rectal air, which affects diagnostic accuracy [12].

To overcome these technical bottlenecks, reduced field-of-view DWI (rFOV DWI) uses two-dimensional selective excitation radiofrequency pulses and optimized phase-encoding strategies to precisely limit the imaging range to the target area [13]. By reducing the FOV, this technique significantly decreases the partial volume effect, enhances the display capability of small lesions, and effectively reduces image artifacts and geometric distortion [14]. Currently, rFOV DWI has been successfully applied in imaging assessments of fine anatomical structures such as the prostate [15], breast [16], and uterus [17], demonstrating unique technical advantages.

This study primarily investigates two aspects: First, systematically comparing the differences in image quality between rFOV DWI and conventional FOV DWI using subjective and objective evaluation systems; Second, deeply exploring the diagnostic efficacy of rFOV DWI for preoperative T staging of rectal cancer, providing evidence-based support for optimizing clinical protocols through imaging assessment.

2. Materials and Methods

2.1 Study Subjects

This study adhered to the Declaration of Helsinki. The research protocol was approved by the Ethics Committee of Qinghai University Affiliated Hospital, and the requirement for informed consent was waived for the subjects (Approval No. P-SL-2024-077).

A total of 47 patients diagnosed with rectal adenocarcinoma via colonoscopy biopsy were enrolled in the study, with data collected from March 2023 to December 2024. Among these, 30 patients underwent comparative image quality analysis. All patients underwent surgery within two weeks after the MRI examination. The study cohort included 25 male and 22 female patients, with an age range of 38 to 79 years and a median age of 62 years.

2.2 Inclusion Criteria

(1) No treatment received before the MRI examination and surgery; (2) Histological biopsy confirmed rectal adenocarcinoma; (3) Complete preoperative MRI examination performed; (4) Complete postoperative pathological results available.

2.3 Exclusion Criteria

(1) History of other tumors; (2) Patients who had received radiotherapy or chemotherapy; (3) Patients with poor image quality; (4) Patients with contraindications to MRI examination; (5) Postoperative pathological diagnosis other than adenocarcinoma.

2.4 MR Image Acquisition

This study used a 3.0 T Achieva superconducting MRI scanner (Philips Healthcare, Netherlands) for image acquisition, employing a 16-channel body phased-array coil for scanning. All patients were scanned in the supine position, head-first. Both rectal rFOV DWI and conventional FOV DWI scans were performed. The specific imaging protocols and parameters were as follows: rFOV DWI scan used TR 2000 ms, TE 67 ms, FOV 160mm × 160 mm, slice thickness 3 mm, slice gap 0.5 mm, matrix 96 × 100; conventional FOV DWI scan used TR 4000 ms, TE 53 ms, FOV 380mm × 320 mm, slice thickness 3 mm, slice gap 0.5 mm, matrix 128 × 100.

2.5 Objective Image Quality Evaluation

Signal-to-noise ratio (SNR) was defined as the ratio of the mean signal intensity within the tumor tissue (Stumor) to the standard deviation of background noise (SDbackground), calculated using the formula: SNR = Stumor / SDbackground.

Contrast-to-noise ratio (CNR) was defined as the difference between the mean signal intensity within the tumor tissue (Stumor) and the mean signal intensity of adjacent normal tissue (Snormal), divided by the square root of the sum of squares of their respective noise standard deviations, calculated using the formula: $CNR = (Stumor - Snormal) / \sqrt{(SDtumor^2 + SDnormal^2)}$.

On the PACS medical imaging workstation, images from the rFOV DWI and conventional FOV DWI sequences with a b-value of 1000 s/mm² were obtained. Signal intensity values and background noise standard deviations were measured for the rectal cancer lesion area, adjacent muscle tissue, and image background. To ensure data reliability, regions of interest (ROIs) were selected avoiding necrotic, hemorrhagic, and cystic areas. Measurement of both image quality parameters was performed independently by two senior abdominal imaging diagnosticians, each with over 5 years of clinical experience, using a double-blind evaluation model. Each physician performed two independent measurements for each parameter of both DWI sequences, and the arithmetic mean of the two measurements was taken as the final value for that parameter.

2.6 Subjective Image Quality Evaluation

This study employed a double-blind imaging assessment design. On the PACS workstation, images from rectal rFOV DWI and conventional FOV DWI at b=1000 s/mm² were selected. Two radiologists with over 5 years of experience in abdominal imaging diagnosis independently completed the image quality assessment, strictly adhering to the blinding principle during the evaluation: the assessing physicians were unaware of the patients' clinical history, endoscopy results, lesion anatomical location, pathological diagnosis, and any other clinical information that might influence judgment. Subsequently, the two groups of images (rFOV DWI and conventional FOV DWI) were independently evaluated and scored, using high-resolution T2-weighted imaging (HR-T2WI) as a reference. The following parameters were used to judge image quality for rFOV DWI and conventional FOV DWI, with a 1-4 point scale used for scoring both groups:

(1) Sharpness (1 = not sharp; 2 = slightly sharp but lacking clarity; 3 = relatively sharp, details discernible; 4 = sharp, details fully displayed);

(2) Image Distortion (1 = severe image distortion, affecting diagnosis; 2 = moderate image distortion, but identifiable; 3 = mild image distortion, not affecting diagnosis; 4 = no image

distortion);

(3) Ghosting, Motion Artifacts, and Susceptibility Artifacts (1 = artifacts severely affect diagnosis; 2 = many artifacts but diagnosis possible; 3 = few artifacts, not affecting diagnosis; 4 = no artifact interference);

(4) Lesion Conspicuity (1 = lesion difficult to identify; 2 = lesion location discernible but borders unclear; 3 = lesion can be identified; 4 = lesion easily detectable with excellent contrast);

(5) Total Image Quality Score (sum of the four scores above).

2.7 ADC Measurement and Evaluation of rFOV DWI Diagnostic Efficacy for Rectal Cancer T Staging

This study employed a double-blind, prospective reading mode. Two physicians, each with over 5 years of experience in abdominal imaging diagnosis, independently completed the image analysis. During the reading process, the diagnosing physicians, blinded to the pathological results and clinical diagnostic information, performed T staging for rectal cancer using rFOV DWI images. In case of disagreement, a consensus was reached through discussion. ADC values were measured by identifying the largest cross-sectional slice of the tumor on axial images from rFOV DWI and conventional DWI sequences, and ROIs were drawn using post-processing software. Subsequently, the ROIs were mapped onto the corresponding ADC maps for quantitative analysis. To minimize measurement errors, the following areas were identified and excluded on T2-weighted images: (1) visibly necrotic and cystic areas; (2) areas with vascular traversal; (3) areas affected by artifacts. The final ADC value for the tumor was taken as the average of measurements from three consecutive slices, with each slice measured three times, and the mean was calculated to minimize operational errors.

2.8 Statistical Analysis

For comparison of image quality parameters between rFOV DWI and conventional FOV DWI: A paired t-test was used to analyze objective indicators (SNR, CNR) between rFOV and conventional FOV DWI techniques. The Wilcoxon signed-rank test was used to evaluate subjective image quality scores between the two DWI sequences and to analyze potential differences in tumor ADC values.

Kappa analysis was used to compare the consistency between rFOV DWI diagnosis and pathological T stage. A kappa value ≤ 0.20 indicated poor consistency; $0.20 <$ kappa value ≤ 0.40 indicated fair consistency; $0.40 <$ kappa value ≤ 0.60 indicated moderate consistency; $0.60 <$ kappa value ≤ 0.80 indicated good consistency; kappa value > 0.80 indicated excellent consistency.

All statistical analyses were performed using SPSS software version 28.0. A P-value < 0.05 was considered statistically significant.

3. Results

3.1 Pathological Results

This study included 47 postoperative pathological specimens of rectal cancer. The distribution of tumor T stages was as follows: T1 stage, 1 case (2.1%); T2 stage, 7 cases (14.9%); T3 stage, 33 cases (70.2%); T4 stage, 6 cases (12.8%). Due to the small number of T1 stage cases (n=1), which might lead to statistical bias, T1 and T2 stage cases were combined into a T1~2 stage group (total 8 cases, 17.0%) for comparative analysis.

3.2 Objective Evaluation of Image Quality

Comparison results of objective image quality parameters between rFOV DWI and conventional FOV DWI are shown in Table 1. Regarding SNR, rFOV DWI (139.86±41.54) showed a significant difference compared to conventional FOV DWI (156.36±35.95) ($P<0.001$). Similarly, the CNR of rFOV DWI (1.87±0.43) was significantly different from that of conventional FOV DWI (2.24±0.45) ($P<0.001$). ADC values measured on the two DWI sequences showed no statistically significant difference (rFOV group 112.50±39.87 vs. conventional group 113.07±40.43, $P>0.05$).

Table 1: Comparison of Objective and Subjective Image Quality Measurement Parameters between Reduced FOV and Conventional FOV Diffusion-Weighted Imaging

Parameter	Reduced FOV DWI	Conventional FOV DWI	P-value
SNR	139.86±41.54	156.36±35.95	<0.001
CNR	1.87±0.43	2.24±0.45	<0.001
ADC value	112.50±39.87	113.07±40.43	0.350
Sharpness	3.47±0.51	2.80±0.66	<0.001
Image Distortion	3.33±0.48	2.53±0.51	<0.001
Artifacts	3.33±0.55	2.67±0.61	<0.001
Lesion Conspicuity	3.50±0.51	2.80±0.81	<0.001
Total Image Quality Score	13.63±1.00	10.80±1.38	<0.001

SNR: signal-to-noise ratio;
CNR: contrast-to-noise ratio;
ADC: apparent diffusion coefficient.

3.3 Subjective Evaluation of Image Quality

Comparison results of subjective image quality parameters (based on the 1-4 point scoring criteria) between rFOV DWI and conventional FOV DWI are also shown in Table 1. rFOV DWI was superior to conventional FOV DWI across all five parameter scores, specifically including: image sharpness (3.47±0.51 vs. 2.80±0.66, $P<0.001$), image distortion (3.33±0.48 vs. 2.53±0.51, $P<0.001$), ghosting, motion artifacts, and susceptibility artifacts (3.33±0.55 vs. 2.67±0.61, $P<0.001$), lesion conspicuity (3.50±0.51 vs. 2.80±0.81, $P<0.001$), and total image quality score (13.63±1.00 vs. 10.80±1.38, $P<0.001$). Scoring examples are shown in Figure 1.

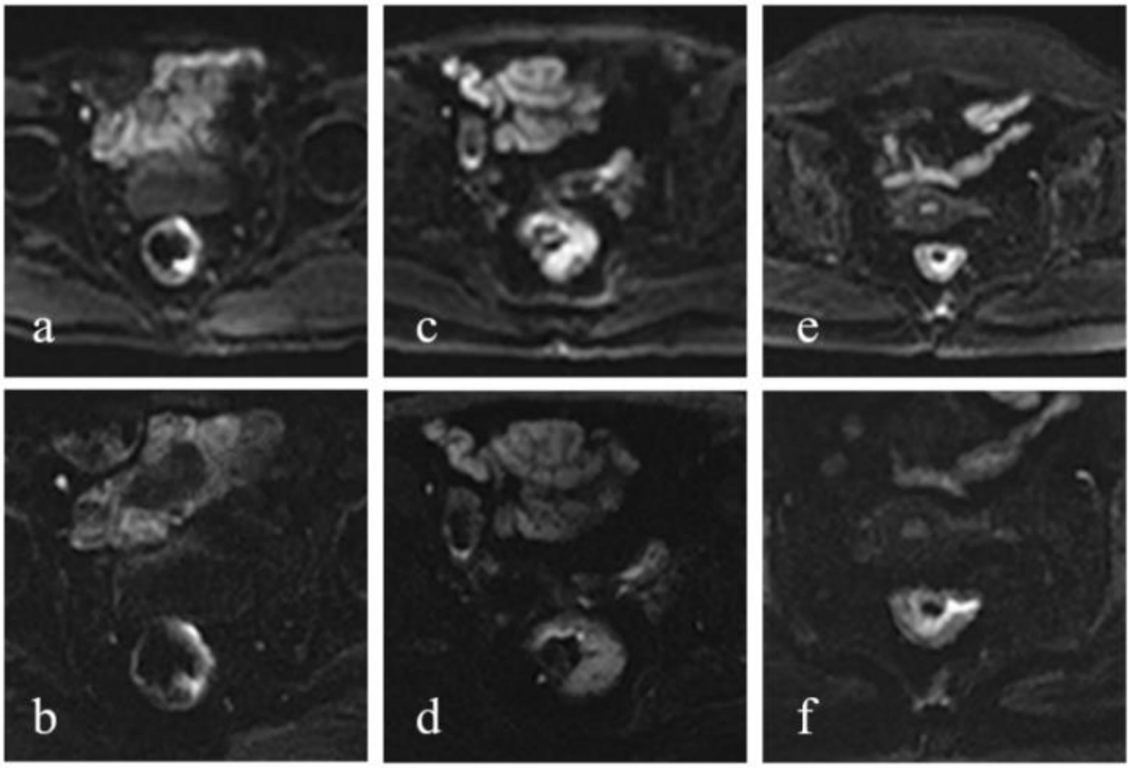

Figure 1: Subjective evaluation images of rectal cancer image quality

Notes: a & b, c & d, e & f are DWI rectal cancer images from three patients, where a, c, e are conventional FOV DWI scans, and b, d, f are rFOV DWI scans; a-b: evaluation of artifacts; c-d: evaluation of lesion sharpness and conspicuity; e-f: evaluation of image distortion. a: Conventional FOV DWI shows mild susceptibility artifacts, not affecting diagnosis. Image quality score 3. b: rFOV DWI shows no significant susceptibility artifacts. Image quality score 4. c: Conventional FOV DWI shows the rectal cancer lesion with heterogeneous signal intensity, lesion location discernible but borders unclear. Image quality score 2. d: rFOV DWI shows the rectal cancer lesion with homogeneous iso-to-low signal intensity; the lesion is easily detectable with excellent contrast. Image quality score 4. e: Conventional FOV DWI shows mild distortion of the lesion. Image quality score 3. f: rFOV DWI shows the lesion clearly, without obvious distortion. Image quality score 4. Comparing the two DWI images, it can be concluded that rFOV DWI images provide significantly clearer anatomical details, less distortion, fewer artifacts, and more conspicuous lesions.

3.4 Comparison of MRI-rFOV DWI T Staging with Pathological T Staging

This study evaluated the diagnostic efficacy of MRI rFOV DWI for tumor T staging. The results showed that the overall diagnostic accuracy of this technique for T staging was 85.1% (40 correctly staged out of 47 cases), demonstrating good consistency with pathological results (Kappa value = 0.650). Among the 7 misdiagnosed cases, 3 were over-staged, and 4 were under-staged. Misdiagnosed cases were primarily concentrated in the T3 stage (see Tables 2 and 3 for details).

Table 2: Comparison of Preoperative T Staging by rFOV DWI and Pathological T Staging (n=47 cases)

MRI stage	Pathological Stage		
	T1~2	T3	T4
T1~2	5	1	1
T3	2	32	2
T4	1	0	3

Table 3: Diagnostic Efficacy of rFOV DWI for Rectal Cancer T Staging [% (n), n=47]

MR T Stage	Accuracy	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value
T1~2	89.3 (42/47)	62.5 (5/8)	94.9 (37/39)	71.4 (5/7)	92.5 (37/40)
T3	89.3 (42/47)	97.0 (32/33)	71.4 (10/14)	88.9 (32/36)	90.9 (10/11)
T4	91.5 (43/47)	50.0 (3/6)	97.6 (40/41)	75.0 (3/4)	93.0 (40/43)

4. Discussion

With the continuous increase in incidence and mortality rates globally, colorectal cancer has become a major public health problem seriously threatening human health. In the field of diagnostic technology, MRI, leveraging its advantages such as superior soft tissue resolution, multi-parametric imaging capabilities, and multiplanar scanning, has become an important imaging modality for early detection and evaluation of colorectal cancer. Therefore, improving the precision of preoperative MRI diagnosis for rectal cancer is of decisive importance for formulating individualized treatment plans. With the continuous development of medical imaging technology, DWI, as the only functional imaging technique currently capable of non-invasively quantifying Brownian motion of water molecules in living tissues, has had its clinical value validated in multiple fields such as the nervous system, breast diseases, and liver lesions. However, conventional full FOV DWI technology, due to its narrow bandwidth in the phase-encoding direction, is highly sensitive to magnetic field inhomogeneities, prone to susceptibility artifacts, image geometric distortion, and blurred details. Particularly in abdominal examinations, affected by multiple factors such as respiratory motion, intestinal peristalsis, and magnetic field heterogeneity, image quality can be significantly degraded, thereby affecting diagnostic accuracy [18]. In stark contrast, rFOV DWI technology, by optimizing scan parameters and imaging sequences, not only significantly improves tissue contrast and spatial resolution but also clearly displays the morphological characteristics of small lesions. This technology can substantially improve the accuracy of T staging assessment for colorectal cancer while enhancing diagnostic sensitivity and specificity. In DWI scanning, while low b-values maintain a high SNR, the signal contrast between tumor tissue and normal bowel wall is insufficient; conversely, while high b-values display lesions more clearly, they lead to a significant reduction in SNR. Literature reports [19] indicate that setting the b-value to 1000 s/mm² achieves an optimal balance between image quality and lesion visualization, facilitating the display of rectal tumor lesions. Therefore, this study used images acquired at b=1000 s/mm² for analysis.

This study demonstrates that in MRI examinations for rectal cancer, rFOV DWI has significant advantages over conventional FOV DWI. The double-blind evaluation results from two senior imaging physicians showed that rFOV DWI scored higher than conventional FOV DWI in terms of image sharpness, distortion, artifacts, conspicuity score, and total image quality score. In terms of subjective image evaluation, rFOV DWI provided higher spatial resolution, reduced distortion, better anatomical structure identification, and clearer lesion border sharpness, corroborating the findings of Peng [20] et al. This improvement is mainly attributed to the rFOV DWI technique's effective reduction of susceptibility artifacts by optimizing sampling in the phase-encoding direction. rFOV DWI was also significantly superior to conventional FOV DWI in objective parameters such as SNR and CNR, a finding consistent with the research of Wu [21] et al.

The ADC value in DWI, as a key quantitative functional imaging parameter, can accurately reflect the microstructural characteristics and pathophysiological changes of lesioned tissue. The ADC value is a comprehensive index quantitatively assessing the degree of restricted diffusion of water molecules and the level of tissue microcirculation perfusion within tissues using a mono-exponential model. In this study, there was no significant difference in ADC values measured for rectal cancer lesions between rFOV and conventional FOV DWI. It is hypothesized that this is because rFOV DWI only improves spatial resolution by reducing the acquisition FOV, having little impact on the ADC value of rectal cancer lesions, consistent with the findings of Peng's team [20]. However, Lu [22] et al. found that the mean ADC value of thyroid lesions in rFOV DWI was significantly lower than that in conventional FOV DWI. Research by Vidiri et al. [23] also found significant differences in ADC values for head and neck tumors measured by rFOV DWI and conventional FOV DWI sequences. The reasons for these differing results may be that many factors influence ADC values, such as the choice of pulse sequence, the selection of b-values, and magnetic field homogeneity and strength; secondly, the pathological characteristics of different tissues and organs (e.g., cell density, stromal component ratio) also affect ADC values. Due to its higher spatial resolution, better fat suppression, and fewer artifacts, the ADC values measured by rFOV DWI may more accurately reflect the true diffusion characteristics of the tissue.

This study used rFOV DWI technology to evaluate preoperative T staging in 47 patients with rectal cancer. The results showed good consistency between the diagnostic results and postoperative pathological staging. Accurate diagnosis was achieved in 40 cases, with 7 misdiagnosed cases, including 3 over-staged and 4 under-staged cases. Over-staging may stem from non-neoplastic factors such as inflammatory reactions around the tumor, local fibrotic changes, or vascular lesions, whose imaging characteristics on MRI can be highly similar to tumor parenchyma, leading to difficulty in differentiation. Under-staging may be due to limitations of MRI in detecting microscopic tumor infiltration. This finding provides a reliable imaging basis for optimizing precise preoperative staging of rectal cancer and is of great significance for guiding clinical decision-making for individualized treatment plans.

Limitations of this study: (1) The number of cases included in this study was relatively small, which might introduce selection bias during parameter measurement. (2) ROI delineation was based on the selection of three consecutive tumor image slices, which may not fully reflect tumor heterogeneity. (3) Only one patient with T1 stage was included; the small number required merging with T2 stage patients for analysis, which might have some impact on the results. Further studies with more cases are needed to confirm the validity and reliability of these findings.

5. Conclusion

rFOV DWI technology provides higher image quality and, due to its significant technical advantages, demonstrates important clinical application value in the T staging diagnosis of rectal cancer. Compared to conventional FOV DWI technology, this technique significantly improves image spatial resolution while reducing distortion. Applying rFOV DWI technology for T staging diagnosis in rectal cancer can further enhance the sensitivity and accuracy of diagnostic results, effectively reducing missed diagnosis and misdiagnosis rates, and providing a reliable imaging basis for precise preoperative staging.

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