Abdominal Radiology (2019) 44:3674–3682
https://doi.org/10.1007/s00261-019-02139-4

SPECIAL SECTION: RECTAL CANCER

Primary and post-chemoradiotherapy staging using MRI in rectal cancer: the role of diffusion imaging in the assessment of perirectal infiltration

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Published online: 22 July 2019

Abstract

Purpose To analyze changes in MRI diagnostic accuracy in main rectal tumor (T) evaluation resulting from the use of diffusion-weighted imaging (DWI), according to the degree of experience of the radiologist.

Methods This is a cross-sectional study of a database including one hundred 1.5 T MRI records (2011–2016) from patients with biopsy-proven rectal cancer, including primary staging and post-chemoradiotherapy follow-up. All cases were individually blindedly reviewed by ten radiologists: three experienced in rectal cancer, three specialized in other areas, and four residents. Each case was assessed twice to detect perirectal infiltration: first, evaluating just high-resolution T2-weighted sequences (HRT2w); second, evaluation of DWI plus HRT2w sequences. Results were pooled by experience, calculating accuracy (area under ROC curve), sensitivity and specificity, predictive values, likelihood ratios, and overstaging/understaging. Histology of surgical specimens provided the reference standard.

Results DWI significantly improved specificity by experienced radiologists in primary staging (63.2% to 75.9%) and, to a lesser extent, positive likelihood ratio (2.06 to 2.87); minimal changes were observed post-chemoradiotherapy, with a slight decrease of accuracy (0.657 to 0.626). Inexperienced radiologists showed a similar pattern, but with slight enhancement post-chemoradiotherapy (accuracy 0.604 to 0.621). Residents experienced small changes, with increased sensitivity/decreased specificity in both primary (69% to 72%/67.2% to 64.7%) and post-chemoradiotherapy (68.1% to 73.6%/47.3% to 44.6%) staging.

Conclusions Adding DWI to HRT2w significantly improved specificity for the detection of perirectal infiltration at primary staging by experienced radiologists and also by inexperienced ones, although to a lesser extent. In the post-neoadjuvant treatment subgroup, only minimal changes were observed.

Keywords Magnetic resonance imaging · Rectal neoplasms · Neoadjuvant chemoradiotherapy · Diffusion-weighted imaging

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Abbreviations

DWI	Diffusion-weighted imaging
HRT2w	High-resolution T2-weighted imaging
CRT	Chemoradiotherapy
ER	Radiologists with previous experience in rectal cancer staging using MRI
NER	Radiologists without experience in rectal cancer staging using MRI
RR	Radiology residents
AUC	Area under the ROC curve
PPV/NPV	Positive/negative predictive values

Introduction

Local assessment of rectal cancer by means of imaging tests is currently considered a necessary practice for therapeutic decision-making [1, 2]. Total mesorectal excision and neoadjuvant treatment with chemoradiotherapy (CRT) have increased the capacity to treat locally advanced cases [3, 4]. MRI has shown good results both for the evaluation of the primary lesion and in determining infiltration of adjacent structures, as well as to check response in post-CRT follow-up [5–9].

Nowadays, the high-resolution T2-weighted sequence (HRT2w) is considered the primary sequence in the study of the main tumor [10–12]. In contrast, the role of diffusion-weighted imaging (DWI) remains controversial [5, 13]: although its potential usefulness for the assessment of response after CRT has been reported, its role in primary staging remains unclear [2, 5]. Despite the fact that some authors claim that DWI does not significantly improve these results [11], the great heterogeneity in the design of the studies published in the literature makes it difficult to draw clear conclusions [7, 11, 14].

Most recently, the focus has been on complete response detection after CRT, and for this, some studies have reported a greater value of DWI [15–17]. However, the presence of perirectal infiltration, either of fat or other structures, also marks an important threshold in treatment decisions: it marks the need of neoadjuvant treatment prior to surgery at primary staging, and the opportunity to apply more conservative surgical techniques in the case of post-CRT downgrading [1, 18, 19].

However, it can be a real challenge to differentiate between desmoplastic reaction and perirectal infiltration, particularly for radiologists with less experience in rectal cancer staging using MRI [20, 21]. Despite this, most published studies have been performed with experienced observers working at highly specialized centers, which means the results could not represent daily practice at most hospitals or that of general radiologists [7, 22]. Since DWI added to T2w sequences may improve rectal cancer detection and delimitation, it is possible that inexperienced radiologists could benefit to a larger extent from such an addition of DWI [23, 24]. This would be an interesting finding to consider during the early stages of learning or in smaller centers.

Therefore, the objective of our study was to evaluate possible changes in the detection of perirectal infiltration in rectal cancer, resulting from the use of DWI added to HRT2w, as compared with the results of using just HRT2w, both in primary and post-CRT staging. Such changes were evaluated in radiologists with different degrees of prior experience in this pathology, to enable us to analyze the usefulness of the additional sequence for each case.

Methods

Patients

The study was approved by the Research Ethics Committee of our hospital. Due to its retrospective nature, informed consent was waived. We performed a cross-sectional study based on MRI records for rectal cancer staging at our hospital (see the workflow in Fig. 1), consecutively adding records since the start of the current decade until we reached a final sample of 100 cases (January 2011–July 2016). Patients who underwent surgery both after primary diagnosis and post-CRT were included in the study. Inclusion criteria consisted of (a) colonoscopy and biopsy-proven rectal cancer; (b) rectal MRI obtained through a correctly performed technique, using the same protocol as all the other MRIs, with all sequences available for review and no significant artifacts; (c) post-CRT follow-up MRI when neoadjuvant treatment was used; and (d) surgery after MRI (total mesorectal excision or abdominoperineal resection) with a complete surgical specimen. At primary staging, the maximum period permitted before surgery was 9 weeks (average: 34.7 days). In post-CRT cases, those with surgery between 6 and 10 weeks after the end of treatment were included (average: 64.1 days). The post-CRT follow-up MRI was the one considered in the study when neoadjuvant treatment was necessary; cases with a period of 5 weeks or less between the end of CRT and the follow-up MRI were excluded (average: 40.7 days).

The need for CRT was evaluated by the Hospital Committee for Colorectal Tumors. When indicated, the neoadjuvant therapy schedule was 825 mg/m^2 of oral capecitabine twice daily, concomitantly with a long cycle of radiotherapy (50.4 Gys in 25 sessions) [25]. Usually, stage IIA cases with superficial infiltration, without factors suggesting poor prognosis, were not considered an indication for CRT; cases where the tumor was located in the upper third of the rectum or rectosigmoid junction were assessed individually.

The histological staging of the surgical specimen was used as the standard of reference. For this analysis, the surgical specimens were fixed in formalin for 24 h. Representative slides were taken from the tumor area. Hematoxylin–eosin staining and immunohistochemical markers were used. Two experienced pathologist (10 and 7 years' clinical experience in the interpretation of colorectal cancer specimens) reviewed all the histopathology slides to determine the histological stage.

MRI protocol

All MRI studies were performed in the same center with a 1.5 T MRI, using a 16-channel phased-array body surface

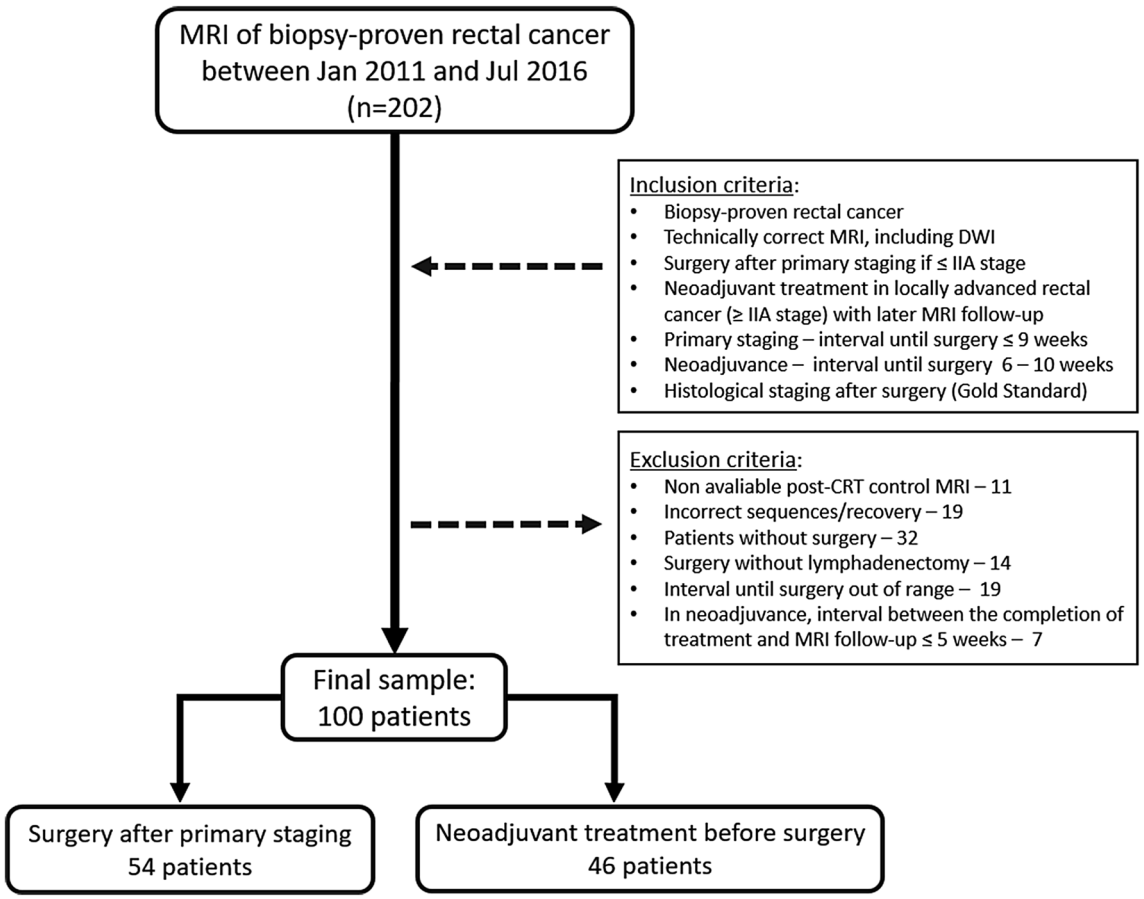

Fig. 1 Workflow chart of the study

coil (MAGNETOM Avanto; Siemens Healthcare). Patients were previously administered 50 ml of gel rectally and 20 mg of butylscopolamine bromide intramuscularly. The MRI protocol included Turbo Spin Eco T2w sequences in the axial, coronal, and sagittal planes, referred to pelvis (TR/TE, 4700/95 ms; 6 mm slice thickness; 256 × 230 matrix; FOV 340; duration 150 s); HRT2w in the three planes, referred to the tumor axis (TR/TE, 4000/95 ms; 3 mm slice thickness; 256 × 230 matrix; FOV 200; duration 135 s); and DWI and apparent diffusion coefficient (ADC) map in the axial plane, referred to pelvis (TR/TE, 5000/70 ms; 5 mm slice thickness; 192 × 115 matrix; FOV 300; b values 50/400/800; duration 200 s).

Image assessment

Images were reviewed on high-resolution monitors using a Picture Archiving and Communication System (General Electric Healthcare). All cases were independently analyzed by ten radiologists, blinded to any information except the presence of biopsy-proven rectal neoplasia. The radiologists had different degrees of experience in rectal cancer staging using MRI: three of them (ER) had previous experience (6, 5, and 3 years; approximately 40 rectal MRI stagings/year); another three of them (NER) had 7, 4, and 2 years' experience reporting MRI, though not in the gastrointestinal area; finally, four radiology residents (RR) in their last years of training had only general knowledge of abdominal MRI (around 10 rectal MRI cases during their training period). Before the start of the study, the inexperienced radiologists and the residents received baseline training (2 h) from an experienced radiologist, which consisted of reviewing and discussion of various imaging examples and cases from our center.

All 10 radiologists were asked to determine the T-stage of the tumor in every patient, according to the American Joint Committee on Cancer (AJCC) 7th Edition guidelines [26]. Every single case was evaluated twice. In the first instance, the radiologists based their evaluation only on HRT2w sequences. The detection of malignancy was based on the presence of foci of thickening/solid masses in the rectal wall and adjacent tissues, with intermediate intensity between the high signal intensity of the fat tissue and the low signal intensity of the muscular layer. The involvement of the

perirectal fat was determined by the inability to visualize the interface between the muscular layer and the perirectal fat, with a rounded or nodular advancing margin and intermediate signal; linear thin speculations within the mesorectal fat with low T2w signal were considered as desmoplastic reaction [27, 28]. Hypointense signals in the post-CRT follow-up MRI indicated fibrosis.

After a minimum one-month washout period, aimed at preventing memory bias, all 10 radiologists evaluated each MRI a second time, now using both HRT2w and DWI. This time, the radiologists were asked to start by checking the DWI by itself, and then to complete the assessment by evaluating the HRT2w again (as main sequence) and giving a joint T-stage (DWI plus HRT2w). The suspicion criterion for malignancy in DWI was the presence of high signal intensity with hypointensity on the ADC map (restricted diffusion).

Statistical analysis

The IBM SPSS Statistics 24.0 (IBM Corp) and Epidat 4.1 (SERGAS, Xunta de Galicia) statistical packages were used for the statistical analysis. In each phase, results were clustered into groups according to the degree of experience, and mean values were calculated. Histological results were dichotomized into T0–T2 and T3–T4, for statistical reasons. This division was decided on after considering the possible changes associated with this threshold in the therapeutic decisions after primary staging or in the surgical technique post-CRT, as well as variations in the prognostic factors that are secondary to the infiltration of structures.

Diagnostic accuracy was measured by calculating the area under the curve (AUC) of the receiver operating characteristic (ROC) for every reading and category (primary staging or post-CRT follow-up). Additionally, sensitivity, specificity, positive and negative predictive values (PPV/NPV), and positive and negative likelihood ratios were obtained for each group. Statistical significance was evaluated by means of Fisher's exact test, and differences for each image set were evaluated with the McNemar test ($p \leq 0.05$ was considered to be statistically significant). Subsequently, intra-group agreement by means of Fleiss's Kappa, and overstaging and understaging rates were calculated for every reading.

Results

The patient sample had an average age of 63 (range 40–85 years) and included 75 men (mean age 65.5 years, range 42–85) and 25 women (mean age 61.4 years, range 40–82). Of the 100 MRI records included in the study, 54 corresponded to primary staging with later surgery (neoadjuvant treatment was not considered necessary) and 46 to post-CRT follow-up before surgery. Anterior approach resection was performed in 80 cases, the other 20 consisted of abdominoperineal resection. The histological results of the surgical specimens yielded 92 cases of adenocarcinoma (3 with just residual cell clusters after CRT) and 8 cases without evidence of remaining tumoral tissue in the surgical piece (4 of these, post-CRT), all of them with demonstrated adenocarcinoma at the initial biopsy. Primary staging based on the surgical specimen showed 4 cases of T0, 25 of T1–2, 20 of T3, and 5 of T4, while post-CRT staging revealed 4 cases of T0, 24 of T1–2, 16 of T3, and 2 of T4.

The results for diagnostic accuracy (AUC), sensitivity, specificity, predictive values, and likelihood ratio are presented in Table 1. All of these were statistically significant ($p < 0.05$), except for the AUC of post-CRT staging by NER without DWI ($p = 0.067$). In evaluation of the differences between the two readings, only the primary staging by the ER subgroup was significant, according to the McNemar test ($p = 0.002$).

In the primary staging by the ER group, adding DWI to HRT2w yielded a marked increase of specificity (12.7%) and the positive likelihood ratio (0.81), with lesser increases in PPV (7.2%) and AUC (0.037), but with a moderate decrease in sensitivity (6.7%). Adding DWI also brought about a marked fall in overstaging (6.8%), but with a slight increase in understaging (3%) (Table 2). In the post-CRT staging category, adding DWI brought with it minimal changes, except for a slight worsening of AUC (0.031). Intra-group agreement improved with the use of DWI, mainly at primary staging (Table 3).

Meanwhile, in the NER group, all the values improved slightly by adding DWI; again, most notably specificity (5.3%), positive likelihood ratio (0.45), and PPV (4.4%) for primary staging, and to a lesser extent AUC (0.036). This group showed a minimal drop of both overstaging and understaging with the use of DWI in both categories, which was more evident in the primary overstaging (2.8%), and a moderate drop in Kappa values.

The RR group also demonstrated slight changes, mainly a small enhancement of sensitivity by adding DWI at both primary staging and post-CRT follow-up (3% and 5.5%, respectively), and a decrease of specificity (3.5%) in the primary staging. There was a slight increase of overstaging and decrease of understaging in all cases, as well as an improvement of intra-group agreement, more marked in the post-CRT category.

Discussion

As it has been previously said, one of the problems with drawing conclusions concerning studies of MRI in rectal cancer is the great heterogeneity in the design of and approach adopted in the different work that is published,

Table 1 Results for accuracy (area under the ROC curve), sensitivity, specificity, positive/negative predictive values, and positive/negative likelihood ratio in the whole MRI series (Global T) and in the subgroups of surgical patients without neoadjuvant (T—primary staging) or after neoadjuvant treatment (yT—post-CRT)

	AUC	Sens. (%)	Spec. (%)	PPV (%)	NPV (%)	PLR	NLR
Global T							
ER							
HRT2w	0.681	77.5	53.8	55.8	76	1.67	0.41
HRT2w + DWI	0.682	72.9	60.8	58.3	74.8	1.86	0.44
NER							
HRT2w	0.654	72.9	54.5	54.5	72.8	1.6	0.49
HRT2w + DWI	0.681	74.8	58	57.1	75.4	1.78	0.43
RR							
HRT2w	0.649	68.6	57.5	54.8	70.8	1.61	0.54
HRT2w + DWI	0.650	72.7	54.8	54.8	72.6	1.6	0.49
T—primary staging							
ER							
HRT2w	0.711	76	63.2	64	75.3	2.06	0.38
HRT2w + DWI	0.748	69.3	75.9	71.2	74.1	2.87	0.4
NER							
HRT2w	0.699	69.2	66.7	64.2	71.4	2.07	0.46
HRT2w + DWI	0.735	70.8	72	68.6	73.9	2.52	0.4
RR							
HRT2w	0.703	69	67.2	64.4	71.5	2.1	0.46
HRT2w + DWI	0.697	72	64.7	63.7	72.8	2.04	0.43
yT—post-CRT							
ER							
HRT2w	0.657	79.6	44	47.7	77	1.42	0.46
HRT2w + DWI	0.626	77.8	45.2	47.7	76	1.42	0.49
NER							
HRT2w	0.604*	78.6	41.2	45.2	75.6	1.33	0.52
HRT2w + DWI	0.621	81	42.6	46.5	78.3	1.41	0.44
RR							
HRT2w	0.588	68.1	47.3	45.3	69.7	1.29	0.67
HRT2w + DWI	0.602	73.6	44.6	46	72.4	1.32	0.59

Results are pooled according to the degree of experience of the radiologist, as well as by the use of just high-resolution T2w sequences or high-resolution T2w plus diffusion-weighted sequences for the evaluation. All results were statistically significant ($p < 0.05$), except for post-CRT staging without DWI by NER ($p = 0.067$)

ER radiologists experienced in rectal cancer MRI staging, *NER* inexperienced radiologists, *RR* radiology residents, *HRT2w* high-resolution T2w sequences, *DWI* diffusion-weighted sequences, *CRT* chemoradiotherapy, *AUC* area under the ROC curve, *Sens* sensitivity, *Spec* specificity, *PPV* positive predictive value, *NPV* negative predictive value, *PLR* positive likelihood ratio, *NLR* negative likelihood ratio

*Result not statistically significant

which evidently hinders comparison [7, 11, 14]. Our results are mostly within the limits established in previously published studies. For detection of perirectal infiltration at primary staging, an AUC of 0.71–0.88 has been reported, with sensitivity of 53.8–85% and specificity of 40–100%, just with HRT2w, while these figures are 0.73–0.84, 62.5–77.8%, and 82.1–94.4%, respectively, for HRT2w plus DWI [11, 20, 24, 29, 30]. Few post-CRT follow-up studies can be reliably compared, since many of them were intended to evaluate only complete response. For perirectal infiltration in this category, AUC, sensitivity, and specificity of 0.45–0.7, 55–67%, and 77–89.8%, respectively, have been reported for HRT2w, and sensitivity of 81–84%/specificity of 11–64% for HRT2w plus DWI [14, 20, 31].

According to the results of our study, the addition of DWI to HRT2w yields some enhancement in evaluation of main tumor primary staging by ER, mainly in specificity and the positive likelihood ratio, at the cost of decreased sensitivity. Lu et al. reported a similar pattern, with an improved specificity (76.9% to 82.1%) and accuracy (71.2% to 78.8%) by adding DWI, but also improved sensitivity (53.8% to 69.2%) [24]. Furthermore, the rise in interobserver agreement has

Table 2 Results for overstaging and understaging in the whole MRI series (Global T) and in the subgroups of surgical patients without neoadjuvant (T—primary staging) or after neoadjuvant treatment (yT—post-CRT)

	Global T		T—primary staging		yT—post-CRT	
	OverSt. (%)	UnderSt. (%)	OverSt. (%)	UnderSt. (%)	OverSt. (%)	UnderSt. (%)
ER						
HRT2w	26.3	9.6	19.7	11.1	34	7.9
HRT2w + DWI	22.3	11.6	12.9	14.1	33.3	8.7
NER						
HRT2w	26	11.6	17.8	14.2	36.3	8.1
HRT2w + DWI	24	10.8	15	13.5	35.4	7.2
RR						
HRT2w	24.2	13.5	17.5	14.3	32	12.5
HRT2w + DWI	25.7	11.7	18.9	12.9	33.6	10.3

The distribution of the groups and pooling by experience is the same as that in Table 1

OverSt overstaging, *UnderSt* understaging, *ER* radiologists experienced in rectal cancer MRI staging, *NER* inexperienced radiologists, *RR* radiology residents, *HRT2w* high-resolution T2w sequences, *DWI* diffusion-weighted sequences

Table 3 Results for intra-group agreement by means of Fleiss' Kappa, in the whole MRI series (Global T) and subgroups of surgical patients without neoadjuvant (T—primary staging) or after neoadjuvant treatment (yT—post-CRT)

	Global	Primary staging	Post-CRT
ER			
HRT2w	0.413	0.405	0.409
HRT2w + DWI	0.491	0.501	0.44
NER			
HRT2w	0.508	0.566	0.38
HRT2w + DWI	0.459	0.503	0.343
RR			
HRT2w	0.403	0.419	0.372
HRT2w + DWI	0.46	0.456	0.451

The distribution of the groups and pooling by experience is the same as that in Table 1

ER radiologists experienced in rectal cancer MRI staging, *NER* inexperienced radiologists, *RR* radiology residents, *HRT2w* high-resolution T2w sequences, *DWI* diffusion-weighted sequences

previously been reported [30]. We also observed a decrease in overstaging when DWI was used, along with a slight increase of understaging. High overstaging rates had been reported as one of the largest problems in evaluation of the main tumor by MRI, mostly due to the difficult differentiation of desmoplastic reaction from superficial tumor infiltration in primary staging [20, 32]. However, DWI has low image resolution, so it is difficult to understand how it could make a difference. It has been suggested that the tumor contour could be evaluated more accurately using DWI, with a better distinction of microvessels or reactive tissue adjacent to the tumor that has a similar signal intensity to it [30]. We hypothesize that, in the doubtful cases, readers could have been influenced by the lack of signs of perirectal infiltration in DWI, and therefore downgraded them (Figs. 2, 3). This would explain both the changes in overstaging and specificity, as well as the slight rise in understaging, and match some small changes that can be appreciated in the raw data.

Meanwhile, minimal changes were detected in the post-CRT follow-up cases. There were also very slight changes in overstaging and understaging, which agreed with those previously reported, except for better HRT2w understaging rates (33%/22% for HRT2w and 23–44%/9–11% for HRT2w plus DWI, respectively) [31, 33]. Previous work reported improvements in the performance of MRI for T-restaging after CRT through the addition of DWI, mostly specifically referring to the differentiation between complete and partial responses to treatment or using T2w (4–5 mm slide thickness) [16, 34–36]. This makes it difficult to correlate those reports with our results, which refer to perirectal involvement. Nonetheless, the sets of results do not contradict each other: due to the secondary changes to CRT, the detection of small foci of a remnant tumor may be much more challenging than that of masses with persistent adjacent tissue infiltration. It is reasonable to think that DWI would be more helpful in such cases.

The NER group demonstrated a slight improvement in their results due to the addition of DWI while maintaining a similar pattern to that observed in the ER: mainly related to specificity, the positive likelihood ratio, and overstaging at the primary staging, despite a decrease of intra-group agreement. It is interesting that, as the ER group, they also showed greater improvement at primary staging MRI, probably due to the same reason. Although they did not have experience in rectal cancer staging, the NER group had prior experience in the use of DWI applied to other areas, so misinterpretations were less likely. Meanwhile, the changes in the RR were variable, but in general were slight with an increase of sensitivity and Kappa values with DWI, as well

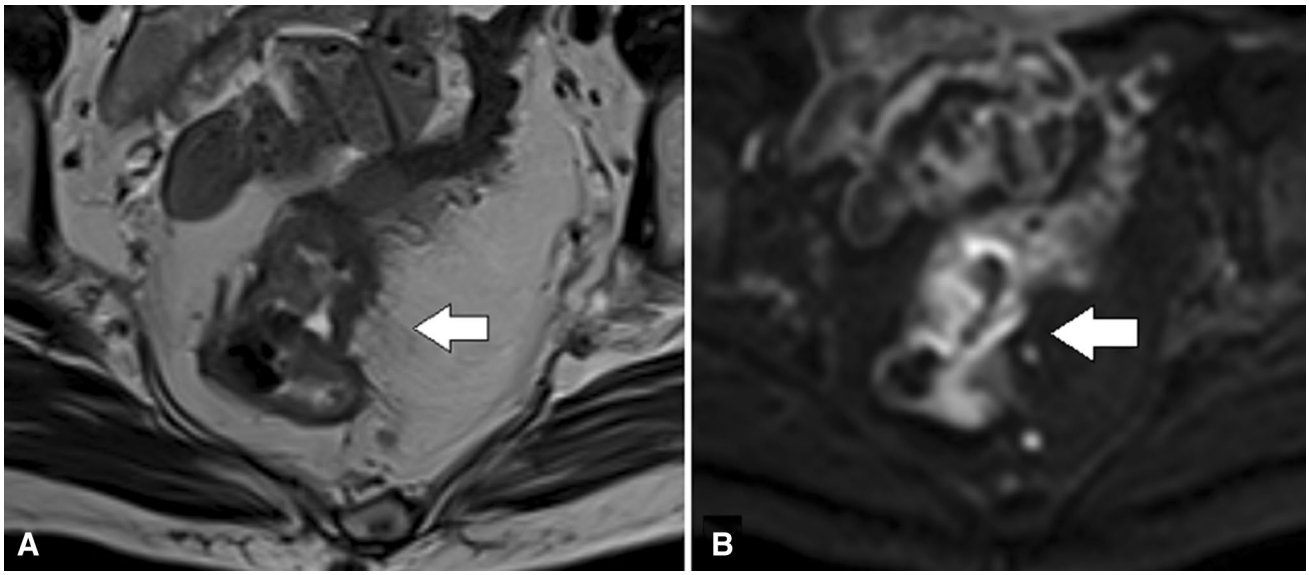

Fig. 2 A 69-year-old man with rectal adenocarcinoma in the upper third, primary staging MRI. It shows moderate fat stranding in high-resolution T2w sequences (**a**) with a mildly blurred outer boundary of the rectal wall (white arrow), which may cause some doubts between desmoplastic reaction and superficial perirectal infiltration. The diffusion-weighted imaging (**b**) demonstrates smooth borders, with no signs of infiltration. Histological results corresponded to stage T2

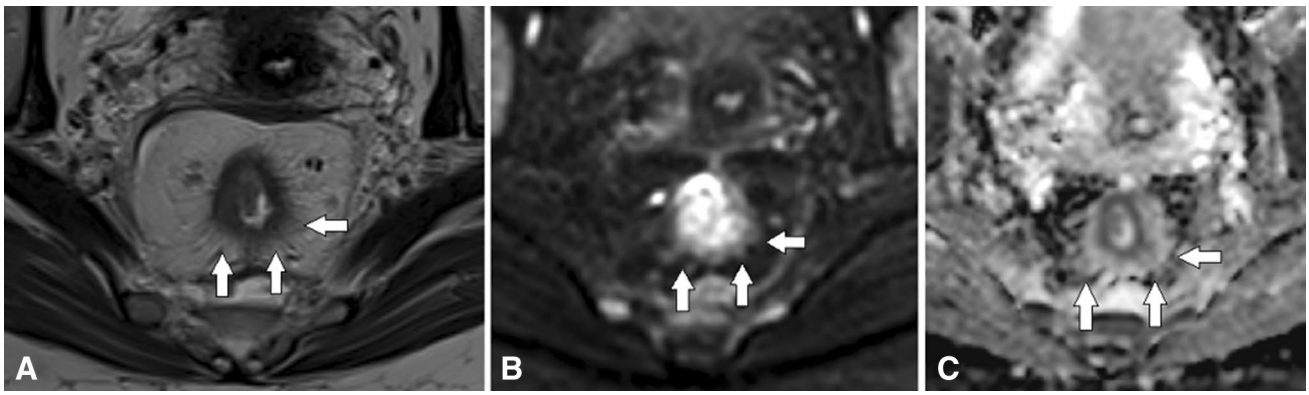

Fig. 3 A 64-year-old woman with rectal adenocarcinoma in the middle third, primary staging MRI. Again, moderate fat stranding with focally undefined outer boundaries of the rectal wall (white arrows) can be observed in the high-resolution T2w sequences (**a**). In this case, hyperintense millimetric lobulations can be seen protruding from the edge in the diffusion-weighted imaging (**b**), which are hypointense in the ADC map (**c**), suggesting infiltration of perirectal fat. Histological results corresponded to stage T3b

as a decrease of understaging, in this case including both primary and post-CRT staging. Since it has been reported that DWI can help to detect and delimitate the viable tumor, these improved understaging rates were not unexpected [24, 34, 36].

We failed to find previous work in the literature that correlates the influence of DWI within groups of radiologists with their different degrees of experience. In a study of the diagnosis of pelvic recurrence in colorectal cancer, Colossio et al. described a significant increase of AUC, sensitivity, and specificity for residents due to the use of DWI, but the comparison is limited because of the different objective and the added use of gadolinium-enhanced sequences [37]. In a study for evaluation of complete response, Sassen et al. reported improved interobserver agreement in rectal cancer staging after the addition of DWI (0.35 to 0.58) between an experienced radiologist and a general one. Despite the enhanced consistency, the experienced radiologist demonstrated the greatest improvement, with only slight changes in the inexperienced one (AUC from 0.77 to 0.89 vs. 0.74 to 0.70, respectively). Once again, the possibility of comparison is limited, as the study evaluated the complete response for the mass and lymph nodes altogether (yT0N0) [38].

Our study had several limitations; firstly, its retrospective nature. Second, the radiologists may have gained experience through participating in the study, in particular, the less experienced ones, and this could have influenced the results. However, learning bias was avoided as far as possible by not providing the observers with feedback on their results. Furthermore, memory bias was prevented by randomized reviews and washout periods between readings. Third, the time interval before surgery was spread over a wide range. This issue remains controversial, just as it was when the study was designed. Ranges from 4 to 12 weeks after CRT have been reported in the literature, but lately, periods of around 8 weeks seem to be the most accepted [1, 5, 25]. Finally, due to the design of the study, only perirectal infiltration was evaluated. The assessment of all other stages would have increased the amount of data in an unacceptable way; however, in our opinion, precisely the difference we studied marks one of the most important thresholds for treatment decisions.

Conclusions

According to the results of our study, adding DWI to HRT2w helps experienced radiologists in the diagnosis of perirectal infiltration in primary staging by improving specificity and decreasing overstaging. It also assists inexperienced radiologists, although to a lesser extent. In the post-neoadjuvant treatment category, only minimal changes were observed, except in residents whose sensitivity increased.

Acknowledgements We would like to thank Christopher Evans for his support with the translation of this work.

Funding This work was partially supported by the Medical College of Las Palmas Foundation [research grant, year 2018].

Compliance with ethical standards

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

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Institutional Review Board approval was obtained in our center.

References

1. Glynne-Jones R, Wyrwicz L, Tiret E, et al (2017) Rectal cancer: ESMO Clinical Practice Guidelines for diagnosis, treatment and follow-up†. *Ann Oncol* 28(suppl_4):iv22-iv40.
2. Tudyka V, Blomqvist L, Beets-Tan RGH, et al (2014) EURECCA consensus conference highlights about colon & rectal cancer multidisciplinary management: The radiology experts review. *Eur J Surg Oncol* 40(4):469–75.
3. Heald RJ, Ryall RD (1986) Recurrence and survival after total mesorectal excision for rectal cancer. *Lancet* 1(8496):1479–82.
4. Heald RJ, Moran BJ, Ryall RD, Sexton R, MacFarlane JK (1998) Rectal cancer: the Basingstoke experience of total mesorectal excision, 1978-1997. *Arch Surg* 133(8):894–9.
5. Beets-Tan RGH, Lambregts DMJ, Maas M, et al (2018) Magnetic resonance imaging for clinical management of rectal cancer: Updated recommendations from the 2016 European Society of Gastrointestinal and Abdominal Radiology (ESGAR) consensus meeting. *Eur Radiol* 28(4):1465–75.
6. Moreno CC, Sullivan PS, Kalb BT, et al (2015) Magnetic resonance imaging of rectal cancer: staging and restaging evaluation. *Abdom Imaging* 40(7):2613–29.
7. Blazic IM, Campbell NM, Gollub MJ (2016) MRI for evaluation of treatment response in rectal cancer. *Br J Radiol* 89(1064):20150964.
8. Allen SD, Padhani AR, Dzik-Jurasz AS, Glynne-Jones R (2007) Rectal carcinoma: MRI with histologic correlation before and after chemoradiation therapy. *Am J Roentgenol* 188(2):442–51.
9. De Nardi P, Carvello M (2013) How reliable is current imaging in restaging rectal cancer after neoadjuvant therapy? *World J Gastroenterol* 19(36):5964–72.
10. Suzuki C, Torkzad MR, Tanaka S, et al (2008) The importance of rectal cancer MRI protocols on iInterpretation accuracy. *World J Surg Oncol* 6(1):89.
11. Zhang G, Cai YZ, Xu GH (2016) Diagnostic Accuracy of MRI for Assessment of T Category and Circumferential Resection Margin Involvement in Patients with Rectal Cancer: A Meta-Analysis. *Dis Colon Rectum* 59(8):789–99.
12. Li XT, Zhang XY, Sun YS, Tang L, Cao K (2016) Evaluating rectal tumor staging with magnetic resonance imaging, computed tomography, and endoluminal ultrasound A meta-analysis. *Med (Baltimore)* 95(44):1–8.
13. Prezzi D, Goh V (2016) Rectal Cancer Magnetic Resonance Imaging: Imaging Beyond Morphology. *Clin Oncol* 28(2):83–92.
14. van der Paardt MP, Zagers MB, Beets-tan RGH, Stoker J, Bipat S (2013) Patients Who Undergo Preoperative Chemoradiotherapy for Locally Advanced Rectal Cancer Restaged by Using Diagnostic MR Imaging : A Systematic Review and Meta-Analysis. *Radiology* 269(1):101–12.
15. Curvo-Semedo L, Lambregts DMJ, Maas M, et al (2011) Rectal Cancer: Assessment of Complete Response to Preoperative Combined Radiation Therapy with Chemotherapy—Conventional MR Volumetry versus Diffusion-weighted MR Imaging. *Radiology* 260(3):734–43.
16. Lambregts DMJ, Vandecaveye V, Barbaro B, et al (2011) Diffusion-Weighted MRI for Selection of Complete Responders After Chemoradiation for Locally Advanced Rectal Cancer: A Multicenter Study. *Ann Surg Oncol* 18(8):2224–31.
17. Song I, Kim SH, Lee SJ, Choi JY, Kim MJ, Rhim H (2012) Value of diffusion-weighted imaging in the detection of viable tumour after neoadjuvant chemoradiation therapy in patients with locally advanced rectal cancer: comparison with T_2 weighted and PET/CT imaging. *Br J Radiol* 85(1013):577–86.
18. Demartines N, von Flüe MO, Harder FH (2001) Transanal endoscopic microsurgical excision of rectal tumors: indications and results. *World J Surg* 25(7):870–5.
19. Visser BC, Varma MG, Welton ML (2001) Local therapy for rectal cancer. *Surg Oncol* 10(1–2):61–9.
20. Vliegen RF a, Beets GL, von Meyenfeldt MF, et al (2005) Rectal cancer: MR imaging in local staging–is gadolinium-based contrast material helpful? *Radiology* 234(1):179–88

21. Jhaveri KS, Hosseini-Nik H (2015) MRI of rectal cancer: An overview and update on recent advances. *Am J Roentgenol* 205(1):W42–55.
22. Lambregts DMJ, van Heeswijk MM, Delli Pizzi A, van Elderen SGC, Andrade L, Peters NHGM, et al (2017) Diffusion-weighted MRI to assess response to chemoradiotherapy in rectal cancer: main interpretation pitfalls and their use for teaching. *Eur Radiol* 27(10):4445–54.
23. Marijnen CAM, Nagtegaal ID, Klein Kranenbarg E, et al (2001) No downstaging after short-term preoperative radiotherapy in rectal cancer patients. *J Clin Oncol* 19:1976–84.
24. Lu Z hua, Hu C hong, Qian W xin, Cao W hong (2016) Preoperative diffusion-weighted imaging value of rectal cancer: Preoperative T staging and correlations with histological T stage. *Clin Imaging* 40(3):563–8
25. Hofheinz R-D, Wenz F, Post S, et al (2012) Chemoradiotherapy with capecitabine versus fluorouracil for locally advanced rectal cancer: a randomised, multicentre, non-inferiority, phase 3 trial. *Lancet Oncol* 13(6):579–88.
26. Colon and Rectum (2011) In: Edge SB, Byrd DR, Compton CC, Fritz AG, Greene FL, Trotti A (eds). AJCC Cancer Staging Handbook: From the AJCC Cancer Staging Manual, 7th edn. Springer International Publishing, New York, pp 143–59.
27. Dewhurst CE, Mortele KJ (2013) Magnetic Resonance Imaging of Rectal Cancer. *Radiol Clin North Am* 51(1):121–31.
28. Iafrate F, Laghi A, Paolantonio P, et al (2006) Preoperative staging of rectal cancer with MR Imaging: correlation with surgical and histopathologic findings. *Radiographics* 26(3):701–14.
29. Fütterer JJ, Yakar D, Strijk SP, Barentsz JO (2008) Preoperative 3 T MR imaging of rectal cancer: Local staging accuracy using a two-dimensional and three-dimensional T2-weighted turbo spin echo sequence. *Eur J Radiol* 65(1):66–71.
30. Feng Q, Yan YQ, Zhu J, Xu JR (2014) T staging of rectal cancer: Accuracy of diffusion-weighted imaging compared with T2-weighted imaging on 3.0 tesla MRI. *J Dig Dis* 15(4):188–94.
31. Van Den Broek JJ, Van Der Wolf FSW, Lahaye MJ, et al (2017) Accuracy of MRI in Restaging Locally Advanced Rectal Cancer After Preoperative Chemoradiation. *Dis Colon Rectum* 60(3):274–83.
32. Chatterjee P, Eapen A, Perakath B, Singh A (2011) Radiologic and pathological correlation of staging of rectal cancer with 3 tesla magnetic resonance imaging. *Can Assoc Radiol J* 62(3):215–22.
33. Suppiah A, Hunter IA, Cowley J, et al (2009) Magnetic resonance imaging accuracy in assessing tumour down-staging following chemoradiation in rectal cancer. *Color Dis* 11(3):249–53.
34. Kim SH, Lee JM, Hong SH, et al (2009) Locally Advanced Rectal Cancer: Added Value of Diffusion-weighted MR Imaging in the Evaluation of Tumor Response to Neoadjuvant Chemo- and Radiation Therapy. *Radiology* 253(1):116–25.
35. Tapan U, Ozbayrak M, Tatli S (2014) MRI in local staging of rectal cancer: an update. *Diagnostic Interv Radiol* 20(5):390–8.
36. Rao SX, Zeng MS, Chen CZ, et al (2008) The value of diffusion-weighted imaging in combination with T2-weighted imaging for rectal cancer detection. *Eur J Radiol* 65(2):299–303.
37. Colosio A, Soyer P, Rousset P, et al (2014) Value of diffusion-weighted and gadolinium-enhanced MRI for the diagnosis of pelvic recurrence from colorectal cancer. *J Magn Reson Imaging* 40(2):306–13.
38. Sassen S, De Booij M, Sosef M, et al (2013) Locally advanced rectal cancer: Is diffusion weighted MRI helpful for the identification of complete responders (ypT0N0) after neoadjuvant chemoradiation therapy? *Eur Radiol* 23(12):3440–9.