RESEARCH

Role of PET/CT in the follow-up of postoperative and/or post-therapy cancer rectum: comparison with pelvic MRI

Mohamed H. Faheem, Evram Nathan[*] and Ahmed Farid Youssef

Abstract

Background: In locally advanced rectal cancer, many imaging modalities are used, for example 18F-2-fluoro-2-de-oxy-d-glucose (18F-FDG) positron emission tomography-computed tomography (PET-CT) and MRI. The aim of our study is to compare the diagnostic accuracy of 18 F-FDG-PET/CT & pelvic MRI; as well as to investigate the possible added value of using combined pelvic MRI and PET-CT for assessment of tumor response.

Results: Regarding the presence of local tumor, both PET CT and MRI showed perfect agreement with 97.1% overall accuracy, while in N category, PET CT showed higher specificity but lower sensitivity than MRI. MRI was superior to PET/CT in detecting extension to nearby organs; owing to the more anatomical details of MRI regarding the involvement of mesorectal fascia and EMVI. Almost total agreement of both MRI and PET/CT was noticed in evaluating post-therapy and postoperative complications.

Conclusion: For locally advanced rectal cancer (pT3–4 N0 M0 or any T N1 M0), a multimodality strategy has been shown to be the best option to evaluate local disease process, using the diagnostic criteria that were based on morphology, as well as glucose uptake, instead of the SUV alone for reassessment of post-therapy or postoperative changes.

Keywords: FDG PET/CT, MRI, T2 WIs, DWIs, Colorectal carcinoma, Chemoradiotherapy (CRT)

Background

Rectal cancer (RC) is considered to be the third most common cancer worldwide and represents 10% of all new cancer diagnoses [1].

Understanding the surgical plans is essential for the radiologist, who should be aware of the different surgical planes performed and types of the resulted anastomosis. The ability to recognize postoperative anatomy is critical to interpret, consequent difficulties to differentiate complications from normal findings [2].

Many modalities are recently used in re-staging and follow-up of LACR after treatment (e.g., MRI and fluoro-deoxyglucose (FDG)-positron emission tomography PET/CT) [1].

It is a great challenge to recognize viable tumoral residual within predominant post-therapy fibrotic changes on the basis of morphologic MR imaging alone. Conventional MR imaging shows low sensitivity for discriminating pathologic complete response from residual tumor [1].

When using 18F-FDG (FDG) PET/CT in evaluation of treatment response or suspected recurrence in RC, depending on the metabolic activity/glycolysis, adequate understanding of the physiological variants, possible artifacts, as well as imaging pitfalls of FDG PET/CT in colorectal cancer patients is extremely important [3].

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The development of high-resolution MRI imaging over the past decade has changed treatment recommendations from using the same strategy of neoadjuvant chemoradiotherapy (nCRT) followed by TME surgery and adjuvant chemotherapy (CT) for all locally advanced tumors (cT3-4 or N + M0) toward a variety of more individualized options [4].

Pelvic MR imaging including High-resolution T2-weighted imaging, plays a role in evaluating response of rectal cancer (restaging), specially in predicting circumferential resection margin (CRM) involvement during restaging of irradiated rectal cancers [5].

Aim of this study

The aim of this study is to compare the diagnostic accuracy of 18 F-FDG-PET/CT & pelvic MRI regarding the assessment of response to Neoadjuvant chemo/radiotherapy in locally advanced rectal cancer and the assessment of postoperative/post-therapy complications, including the radiological signs of local tumoral recurrence; as well as to investigate the beneficial value of potential application of simultaneous MRI and PET-CT for these patients.

Patients and methods

This is prospective cross-sectional study. We studied 35 patients from Egypt who presented to a "Private radiology center" for monitoring treated rectal/ano-rectal cancer and underwent MRI & 18F-FDG-PET/CT examination, during the period from January 2019 to February 2022.

Our study included 35 patients known to have rectal cancer; 9 females and 26 males (Table 1). Twenty-four patients had received CRT and eleven underwent post treatment surgery.

Inclusion criteria

1. Known patient with locally advanced cancer rectum (T3 & T4 category) who received neoadjuvent chemo-/ radio-therapy (for down staging).

Table 1 Demographic characteristics of the studied patients

Demographics		
Age (years)	Mean ± SD	50 ± 16
Gender		
Males	*n* (%)	26 (74.3)
Females	*n* (%)	9 (25.7)

2. Known patient with cancer rectum who underwent surgical resection with free resection margin.

Exclusion criteria

1. Patients with known contraindications to perform 18F-FDG-PET/CT &/or MRI, e.g., pregnancy, cardiac pacemaker, etc.
2. Patients who had no pathological data.
3. Pathologically proven patients but did not receive therapy or underwent surgery.

Methods

The study included 35 patients known to have rectal cancer (24 patients had received CRT and 11 patients who underwent post treatment surgery).

All patients underwent 18F-FDG-PET/CT and MRI (T2 WIs and DWIs) to evaluate treatment response (including T and N category); as well as operative bed complications; followed by a third short interval follow-up imaging study as a reference standard (about 3–6 months for post CRT patients; however for postoperative patients it was about 9–12 months), because pathological reference during the treatment course is not routinely done.

Informed consent was taken from all the sample patients, that they were informed about their participation in the study, and they were told that the confidentiality of their personal data was preserved.

Procedures

For post CRT patients, examinations were done 6–8 weeks after Last chemotherapy session, while for postoperative patients, examinations were done 3–6 months after surgery.

Whole body 18F-FDG-PET/CT studies were performed. The Scanner used in this study is GE Discovery STE 16 PET/CT Scanner. Patients were instructed to fast for at least 4 h before imaging and they received intravenous IV 18F-FDG in dose of (0.125 mCi/kg). Blood glucose level (BGL) measured in the day of the study and was less than 200 mg%. Imaging was performed at 50 to 70 min after injection. PET, PET/CT, and CT images were reviewed using a dedicated workstation and software.

MRI was performed using a 1.5-T scanner (GE SIGNA voyager 1.5 T MRI) (Siemens MAGNETOM Aera1.5 T MRI). Consecutive axial/coronal/Sagittal sequences high-resolution T2-WIs (TR = 6440 ms & TE = 113 ms) were acquired; as well as axial Diffusion Weighted Images (DWIs) (using *b* value of 50–450–800 s/mm^2) and ADC

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images were obtained (ADC values were not measured in our study).

Interpretation of PETCT and MRI findings

(a) Interpretation of PET/CT using Qualitative(visual) and quantitative (SUV max)assessment were done for both T and N category.
(b) Interpretation of MRI findings with restaging for T and N category, depending on T2/DWIs signal of the primary tumor; as well as signal (eg: mixed signal), size (> 5 mm in diameter) and shape (irregular borders) of the regional lymph nodes.
(c) Comparison between PET/CT and MRI findings was done
(d) A short interval (3–6 months) imaging study was obtained as a reference standard (especially for patients with viable tumor in the previous studies); however some of the postoperative patients who showed negative previous PETCT study; did a follow-up study after 9–12 months.

Results

Our study included 35 patients known to have rectal cancer; 9 females and 26 males (Table 1). Twenty-four patients had received CRT and eleven underwent post treatment surgery.

PET CT findings

18 patients (51.4%) showed a metabolically active local tumor. Twelve patients (34.3%) had metabolically active Lymph nodes. Seven patients (20%) showed extension to nearby structures. Six patients (17.1%) showed post-radiotherapy complications, and 7 of 11 patients who underwent surgery (63.6%) showed postoperative complications (Table 2).

MRI findings

Eighteen patients (51.4%) showed a viable local tumor. 19 patients (54.3%) had Lymph nodes affected. 13 patients (37.1%) showed extension to nearby structures. Seven patients (20.0%) showed post-radiotherapy complications, and 7 of 11 patients who underwent surgery (63.6%) showed postoperative complications (Table 3).

Follow-up findings

Nineteen patients (54.3%) showed a local tumor. 14 patients (40.0%) had Lymph nodes affected. Thirteen patients (37.1%) showed extension to nearby structures. Seven patients (20.0%) showed post-radiotherapy complications, and 7 of 11 patients who underwent surgery (63.6%) showed postoperative complications (Table 4).

Agreement of PET CT and MRI findings with follow-up findings

As regards PET CT agreement with the follow-up findings, it showed excellent agreement regarding the presence of local tumor ($K = 0.943$) and post-radiotherapy complications ($K = 0.906$). In addition, it showed perfect agreement regarding postoperative complications ($K = 1.0$). Furthermore, it showed good and very good agreement regarding the extension to nearby structures ($K = 0.595$) and lymph nodes affection ($K = 0.756$), respectively.

Table 3 MRI findings of the studied patients

	n (%)
Viable local tumor	18 (51.4)
Lymph nodes	19 (54.3)
Extension to nearby structures	13 (37.1)
Post radiotherapy complications	7 (20.0)
postoperative complications*	7 (63.6)

*Percentage was calculated based on total 11 patients underwent surgery

Table 2 PET CT findings of the studied patients

	n (%)
Metabolically active local tumor	18 (51.4)
Metabolically active Lymph nodes	12 (34.3)
Extension to nearby structures	7 (20.0)
Post radiotherapy complications	6 (17.1)
Postoperative complications*	7 (63.6)

*Percentage was calculated based on total 11 patients underwent surgery

Table 4 Follow-up findings of the studied patients

	n (%)
Proved local tumor	19 (54.3)
Lymph nodes	14 (40.0)
Extension to nearby structures	13 (37.1)
Post radiotherapy complications	7 (20.0)
Postoperative complications*	7 (63.6)

*Percentage was calculated based on total 11 patients underwent surgery

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As regards MRI agreement with the follow-up findings, it showed excellent agreement regarding the presence of local tumor ($K = 0.943$). In addition, it showed perfect agreement regarding the extension to nearby structures, postoperative complications, and post-radiotherapy complications ($K = 1.0$ for each). Furthermore, it showed very good agreement regarding lymph nodes affection ($K = 0.719$) (Table 5).

Diagnostic indices of PET CT and MRI

Regarding the presence of local tumor, PET CT showed 94.7% sensitivity, 100% specificity, 100% PPV, 94.1% NPV, and 97.1% overall accuracy, while MRI showed 94.7% sensitivity, 100% specificity, 100% PPV, 94.1% NPV, and 97.1% overall accuracy.

Regarding lymph node affection, PET CT showed 78.6% sensitivity, 95.2% specificity, 91.7% PPV, 87% NPV, and 88.6% overall accuracy, while MRI showed 100% sensitivity, 76.2% specificity, 73.7% PPV, 100% NPV, and 85.7% overall accuracy.

Regarding extension to nearby structures, PET CT showed 63.8% sensitivity, 100% specificity, 100% PPV, 78.6% NPV, and 82.9% overall accuracy, while all indices were 100% in MRI.

Regarding post-radiotherapy complications, PET CT showed 85.7% sensitivity, 100% specificity, 100% PPV, 96.6% NPV, and 97.1% overall accuracy, while all indices were 100% in MRI.

Regarding postoperative complications, all indices were 100% in PET CT and MRI (Table 6).

Statistical methods

Data management and statistical analysis were done using SPSS version 25. (IBM, Armonk, New York, United States). Quantitative data were summarized as means and standard deviations. Categorical data were summarized as numbers and percentages. Agreement of PET CT and MRI findings with follow-up findings were assessed using Kappa measure of agreement. Diagnostic indices of PET CT and MRI were calculated. All statistical tests were two-sided. *P* values less than 0.05 were considered significant.

Discussion

The most important treatment strategy for CRC in the early stage is potentially curative surgery.

There are different conditions that occur after preoperative CCRT. The radiation-induced changes in the rectal wall and in the lymph nodes render the assessment of preoperative restaging difficult [6].

Low et al., stated that the reasons for overstaging, were due to desmoplastic peritumoral inflammation, which remains a challenge on CT, as with the other modalities (MRI) [7].

Neoadjuvant CRT helps to decrease tumor volume and stage, thus increasing the chance for potential resectability and sphincter conservation. However, metabolic response shown by FDG-PET typically occurs before

Table 5 Agreement of PET CT and MRI findings with follow-up findings

	PET CT		MRI	
	Kappa	*P* value	Kappa	*P* value
Presence of local tumor	0.943	< 0.001	0.943	< 0.001
Lymph node affection	0.756	< 0.001	0.719	< 0.001
Extension to nearby structures	0.595	< 0.001	1.0	< 0.001
Post radiotherapy complications	0.906	< 0.001	1.0	< 0.001
Postoperative complications	1.0	0.001	1.0	0.001

Table 6 Diagnostic indices of PET CT and MRI

		Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	OA (%)
Presence of local tumor	PET CT	94.7	100	100	94.1	97.1
	MRI	94.7	100	100	94.1	97.1
LN affection	PET CT	78.6	95.2	91.7	87	88.6
	MRI	100	76.20	73.7	100	85.7
Extension to nearby structures	PET CT	53.8	100	100	78.6	82.9
	MRI	100	100	100	100	100
Post radiotherapy complications	PET CT	85.7	100	100	96.6	97.1
	MRI	100	100	100	100	100
Postoperative complications	PET CT	100	100	100	100	100
	MRI	100	100	100	100	100

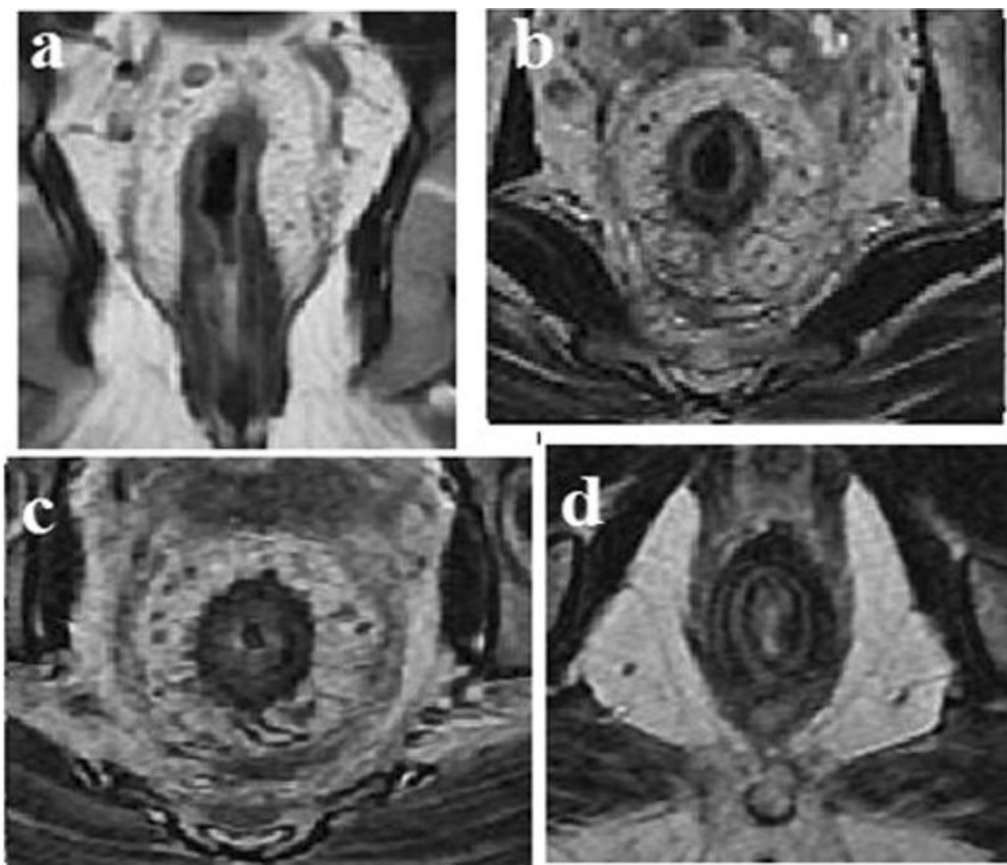*PPV* positive predictive value, *NPV* negative predictive value, *OA* overall accuracy

Fig. 1 a–d MRI study for a 39 years old male with anorectal mucinous carcinoma and received CRT. Coronal (**a**) and Axial (**b–d**) T2 WIs, revealed circumferential diffuse hypointense signal of the rectal wall/anal canal with mild submucosal hyperintense T2 signal (interpreted as post-therapy fibrotic changes with mild submucosal edema). Stranding appearance/smudging of the mesorectal fat planes and mildly thickened hypointense mesorectal fascia. Intact external anal sphincters and levator ani

a decline in volume and is considered more useful for assessment of therapy response than findings obtained with other modalities [6].

Therefore, the use of 18F-FDG PET scans to predict the response of rectal cancer to preoperative CCRT has been investigated. As this diagnostic modality visualizes the distribution of glucose uptake and the increased glucose metabolism in tumor cells [8].

Lambregts et al., study revealed MRI limitation to distinguish sterilized fibrosis from fibrosis with viable tumor and subsequent inability to identify complete responders. However; addition of diffusion-weighted imaging to the MR protocol improved the performance to discriminate between tumor and fibrosis, but certain pitfalls need to be taken into account. Knowledge of specific patterns of morphology and diffusion signal can help to further optimize diagnostic performance [9].

The 2016 ESGAR (European Society of Gastrointestinal and Abdominal Radiology) had generally accepted evaluated available literature and determined that T2 dark (fibrotic scar) appearance post-CRT or normal appearing rectal wall post-CRT, in conjunction with resolution of abnormal DWI signal, was highly predictive of complete or near-complete tumor response [10].

Zixuan Zhuang et al., concluded that depending on MRI in the detection of lymph node metastasis is inadequate either through using morphological criteria or shorter diameter. Therefore a variety of imaging methods should be combined to determine the optimal treatment strategy [11].
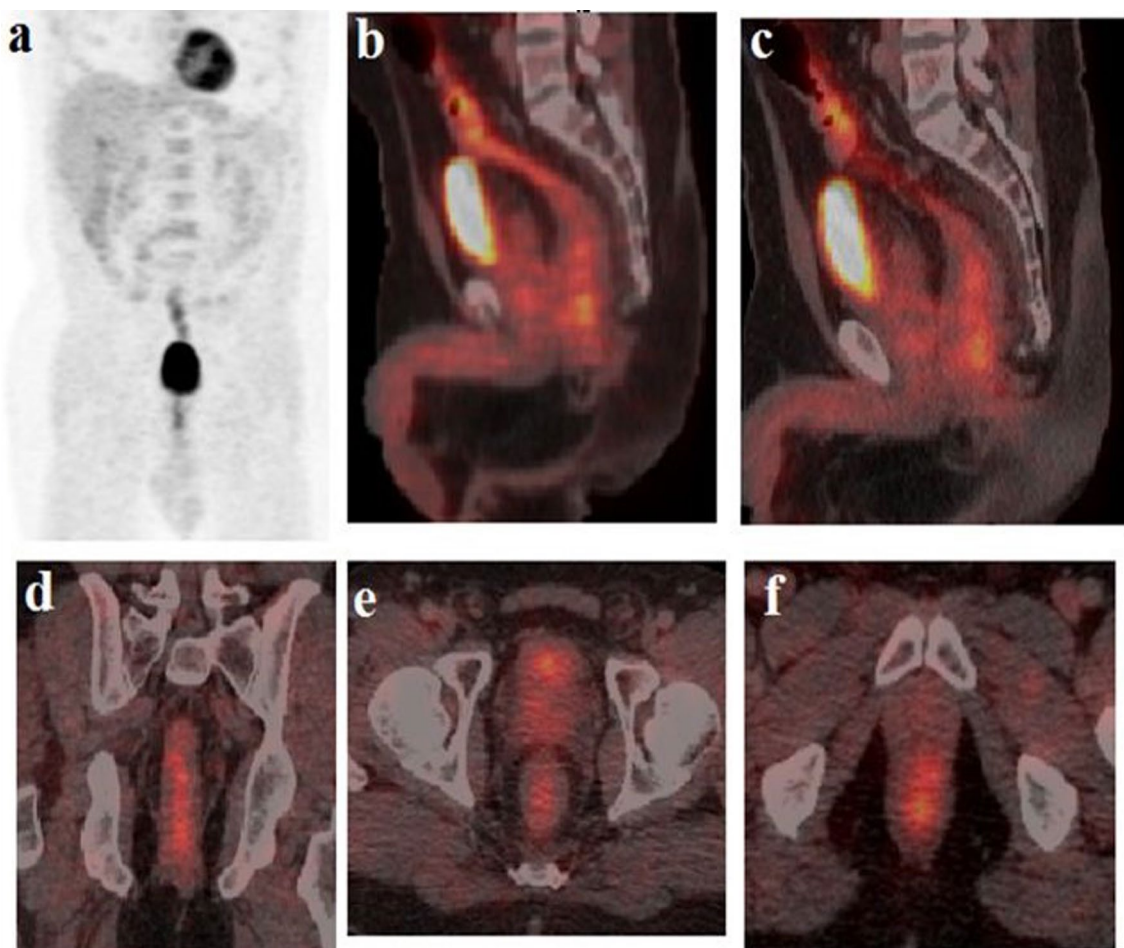
Fig. 2 **a–f** PET/CT study for the same patient in Fig. 1. **a** MIP, **b–f** sagittal, coronal and axial Fused PET-CT images revealed: Long segment of diffuse central low grade FDG uptake seen involving the rectum and anal canal (max. SUV ~ 4) (likely post therapeutic sequelae); however a focal eccentric area of slightly higher FDG uptake ((max. SUV ~ 5) is seen involving the lower rectum at 6–7 O'clock (worrisome about residual viable tumoral lesions), for close follow-up

Hiroto Murata et al., stated that the maximum standardized uptake value (SUVmax) and SUVmax normalized to liver uptake (SLR) after CRT showed the highest sensitivity (90%); as well as the decreasing rate of SUVmax and SLR demonstrated the highest specificity (89%) for pCR [12], while Park et al. reported that SLR after CRT was a more accurate predictor of pCR than SUVmax [13].

Yong Beom Cho et al. conducted a study to investigate the accuracy of MRI and 18F-FDG PET/CT for restaging after preoperative CCRT for rectal cancer, 30 patients with histologically proven rectal adenocarcinoma were included in this study. All patients received preoperative CCRT and they underwent surgical resection after its completion [14].

In 2020, another retrospective study was done by Yan Li et al. investigating the diagnostic performance of PET/MR and MR alone in locoregional T and N Staging on 23 patients with rectal cancer, comprising 9 for primary and 14 for preoperative post-CRT restaging [15].

Xiaoxuan Jia et al., also conducted a retrospective study using MRI and pathological data from 57 registered patients who underwent neoadjuvant treatment and total mesorectal excision between August 2015 and July 2018. The sensitivity and specificity of restaging MRI in determining tumor regression grade, T category, N category, circumferential resection margin, and extramural
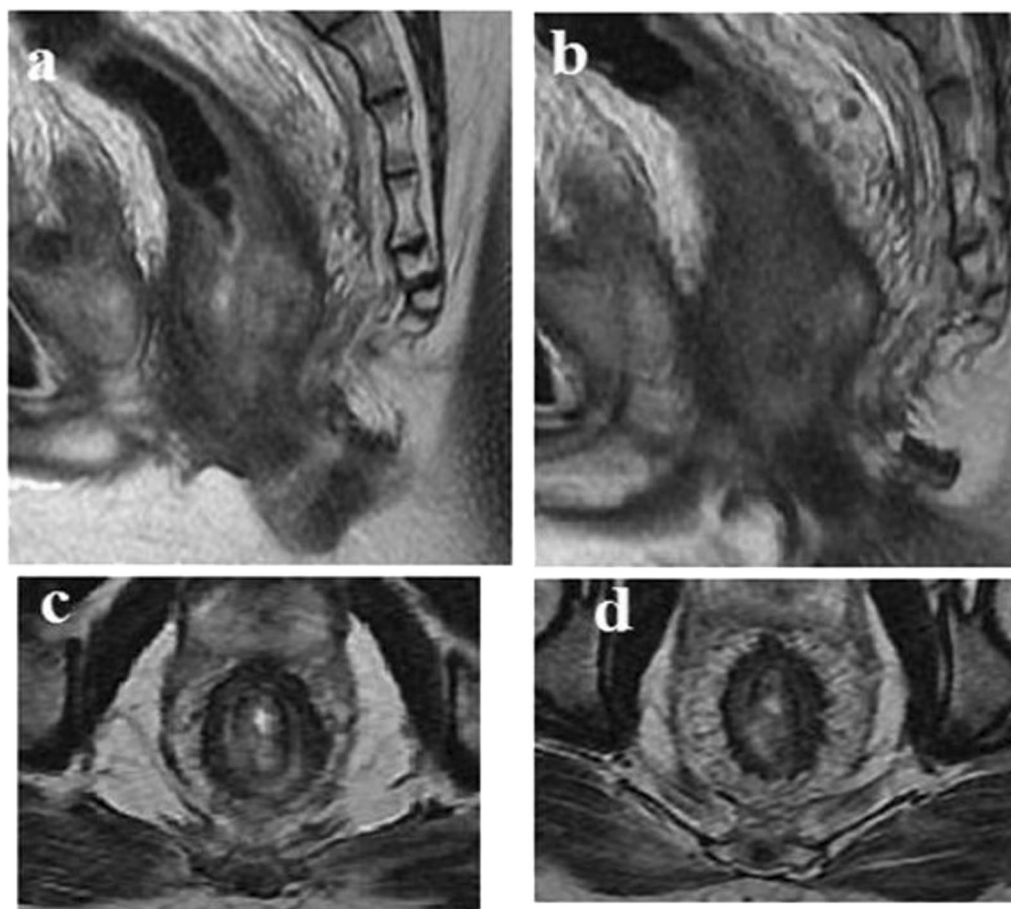
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Fig. 3 **a–d** Follow-up MRI study for same patient in Fig. 1. **a, b** sagittal T2 WIs, **c, d** axial T2 WIs, revealed better delineation of focal area of intermediate T2 signal seen involving the lower rectum (correlated to the same area found on the PET CT scan, 6–7 O'clock) and showing size progression as well, confirming the viable tumoral growth that was missed on the previous MRI due to the predominant fibrotic signal

vascular invasion were correlated with pathology results as the reference standard [16].

In the present study, we compared 18F-FDG PET/CT and MRI findings in 35 patients (24 patient received CCRT and 11 postoperative patients), and verifying their findings by comparison to a short interval follow-up imaging studies. We assessed their accuracy in detecting residual/ recurrent viable tumor, lymph nodes, extension to nearby structures, post-therapy changes and postoperative complications.

In our study, MRI showed 94.7% sensitivity, 100% specificity, 100% PPV, 94.1% NPV, and 97.1% overall accuracy with excellent agreement regarding the presence of local

tumor ($K = 0.943$) (19 of 18 patients on follow-up study) with one patient was under staged (Figs. 1, 2, 3).

Regarding the N category, MRI showed 100% sensitivity, 76.2% specificity, 73.7% PPV, 100% NPV, and 85.7% overall accuracy with very good agreement regarding lymph nodes affection ($K = 0.719$) (14 of 19 positive patients on follow-up study). MRI morphologic criteria to interpret lymph node involvement differed between before and after CRT e.g.,: border irregularities, size and heterogeneous SIs criteria, were found to be unreliable predictors for determining malignant nodes (Figs. 4, 5, 6).

In addition, MRI showed perfect agreement (all indices were 100%) regarding the extension to nearby structures,
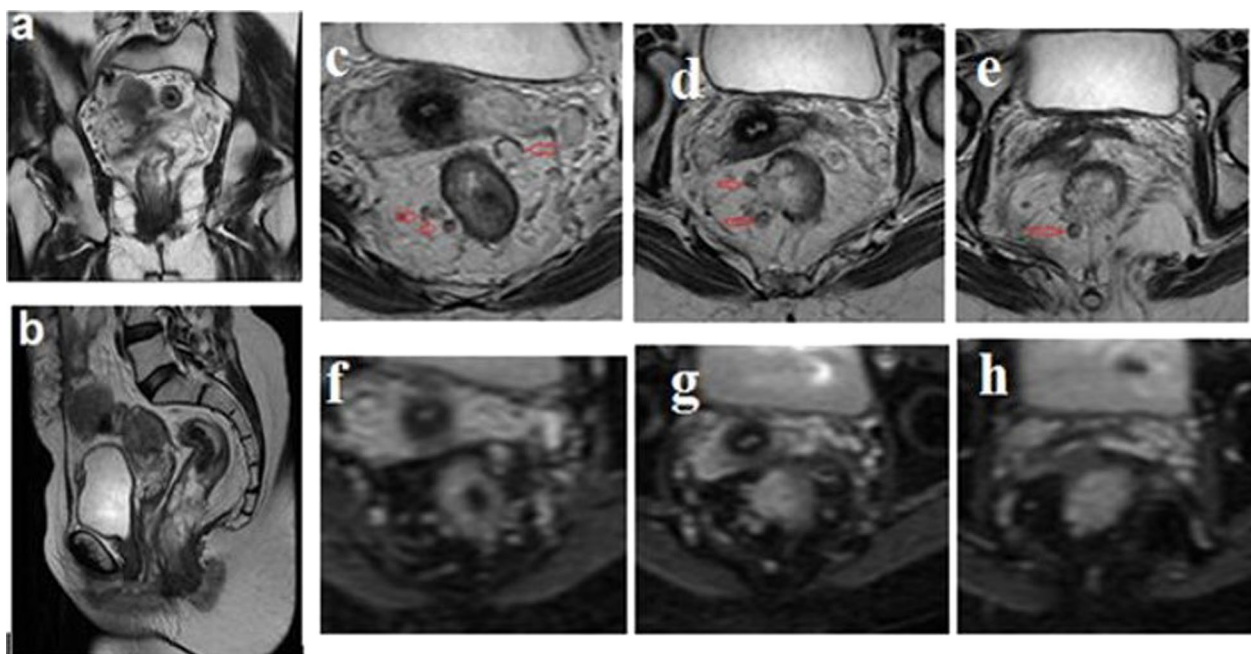
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Fig. 4 a–h MRI study for 40 years *old Female with pathologically proven cancer rectum and received radiotherapy*. **a, b** coronal and Sagittal T2 WIs, **c–e** axial T2 & **f–h** DWIs, revealed irregular polypoidal mural thickening is seen involving the lower 2/3 of the rectum, involving the anorectal junction; with surrounding fat smudging; however no evidence of MRF infiltration with clear intervening fat plans. The lesion displays mixed T2 signal with the intermediate signal representing the tumoral residual while the hypointense signal denoting fibrotic changes. Multiple enlarged mesorectal and internal iliac lymph nodes are seen measuring up to 1.2 cm, displaying intermediate T2 and mild hyperintense signal on DWIs

postoperative complications, and post-radiotherapy complications ($K = 1.0$ for each).

Yong Beom Cho et al. concluded lower overall accuracy of the MRI in the T category was 67%, whereas overstaging and under staging occurred in 30 and 3% of the patients, respectively ($j = 0.422$, $P = 0.003$). The MRI scans could not predict anyone who showed a pathologic complete response after preoperative CCRT. For the N category, their results also showed lower accuracy in staging (75%, 21 of 28 patients), whereas 14% of the patients were over staged and 11% were under staged ($j = 0.410$, $P = 0.030$). Kappa statistics showed a moderate degree of agreement between the post-CCRT MRI and the pathologic stages [14].

In Yan Li et al. study, two patients were over staged, due to misinterpretation of the desmoplastic reaction at T2 stage tumor border as extramural tumor invasion, which is a common and well-known obstacle in staging. They found that the sensitivity of T2WIs imaging in patients after CRT was markedly reduced from 85 to 66%, with estimated sensitivity of only 55% in differentiating

between T0-2 and T3-4 stages. In predicting ypT3-4 stage, the diagnostic performance was sensitivity 66%, specificity 100% and accuracy 78%. While combining the additional PET information with T2WIs imaging, the determination of T stages in each patient showed accuracy of 75% in predicting T3-4 stages 75%. The combined reading of PET and T2WIs did not help improve the diagnostic accuracy due to the lower spatial resolution of PET and overlap of tumor glucose metabolism between post-CRT yT0-2 and yT3-4 stages [15].

Xiaoxuan Jia et al. results regarding MR alone were low compared to the current study results. They found that the sensitivity and specificity of MRI alone in determining tumor regression was 77.1% & 72.7% with the accuracy of mrTRG was 77.2%. They also found that the sensitivity and specificity of MRI alone in determining node-positive disease 75.0% & 70.7% with the accuracy of ymrN categorization was 71.9% (41/57), whereas for circumferential resection margin 87.5% & 85.7% with overall accuracy 86%; and extramural vascular invasion 91.7%
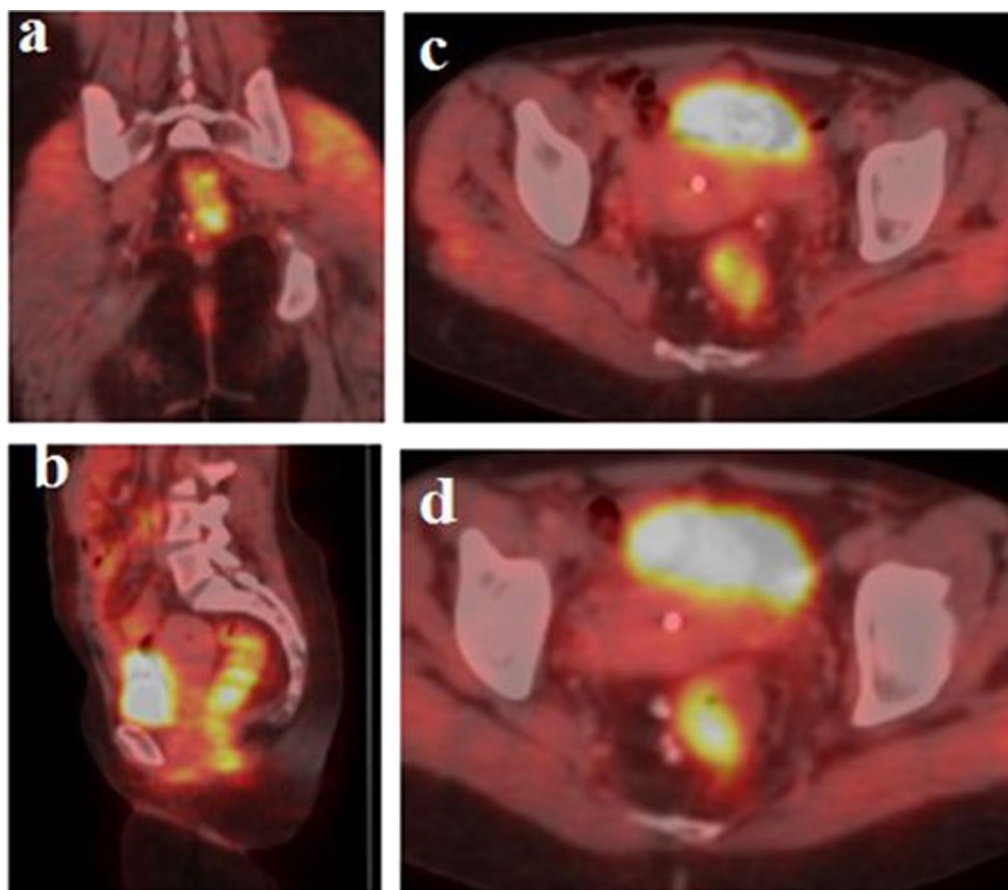
Fig. 5 **a–d** PET-CT study for the same patient in Fig. 4. Fused PET/CT images **a, b** coronal and sagittal, **c, d** axial images, revealed excellent agreement with MRI regarding the T category; showing metabolically active circumferential polypoidal mural thickening of the lower 1/2 of the rectum/ anorectal junction seen with max SUV ~ 5.38. However PETCT showed complete disagreement with MRI regarding the nodal assessment; as PET/CT revealed mostly calcified metabolically inactive (non FDG avid) mesorectal lymph nodes measuring up to 1.3 cm (regardless their shape, number and size)

& 64.4% with accuracy of ymrEMVI was 47.4% (27/57) [16].

In Xiaoxuan Jia et al. study, MRI was prone to over-staging of disease. They postulated that the discrepancies between MRI and pathologic findings were mainly caused by misinterpretation of fibrotic areas as residual tumor. Inflammatory cell infiltration and pure mucin could appear as high signal intensity in fibrotic areas on DW images, an appearance similar to that of residual tumor. Edematous mucosa and submucosa adjacent to the tumor and muscularis propria could also be mistaken for residual tumor because of their intermediate signal intensity on T2-weighted MR images [16].

Regarding the presence of local tumor, 18F-FDG PET/CT showed 94.7% sensitivity, 100% specificity, 100% PPV, 94.1% NPV, and 97.1% overall accuracy with excellent agreement regarding the presence of local tumor ($K = 0.943$) (19 of 18 patients on follow-up study with one patient was under staged).

Regarding lymph node affection, 18F-FDGPET/CT showed 78.6% sensitivity, 95.2% specificity, 91.7% PPV, 87% NPV, and 88.6% overall accuracy, it showed very good agreement regarding the lymph nodes affection ($K = 0.756$), respectively (12 of 14 patients on follow-up study).
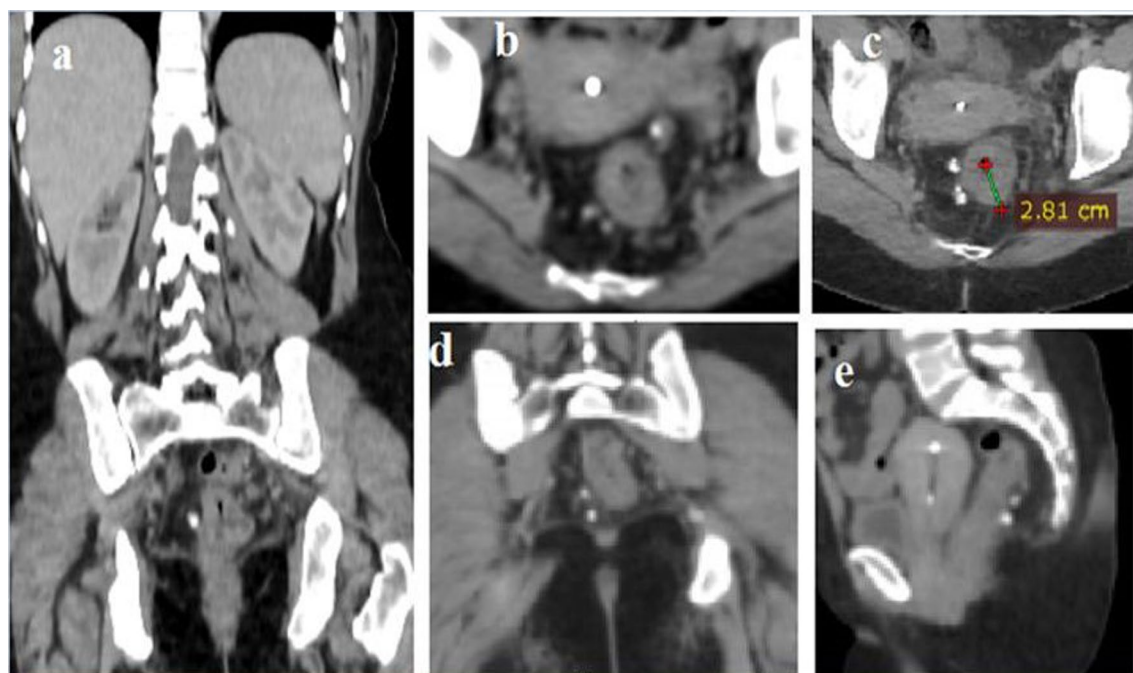
Fig. 6 **a–e** Follow-up Post contrast CT study for the same patient in Fig. 4. **a–e** coronal, axial and sagittal images revealed: slight progression of the rectal disease process regarding the maximum thickness (2.8 cm, compared to 2.5 cm on the previous scan); (which could be pseudo-progression due to cystic or mucinous degeneration of the primary tumor; rather than actual viable tumoral progression, this considered a limitation of conventional CT alone). However, no appreciable size or number changes regarding the previously noted calcified LNs, confirming on viable nodal lesions

Regarding extension to nearby structures, 18F-FDG PET/CT showed 53.8% sensitivity, 100% specificity, 100% PPV, 78.6% NPV, and 82.9% overall accuracy, with good agreement regarding the extension to nearby structures ($K=0.595$) (7 of 13 patients on follow-up study).

Regarding post-radiotherapy & postoperative complications, PET CT showed 85.7–100% sensitivity, 100% specificity, 100% PPV, 96.6–100% NPV, and 97.1–100% overall accuracy, respectively, with excellent agreement regarding the post-radiotherapy complications ($K=0.906$) and perfect agreement regarding postoperative complications ($K=1.0$) (6 & 7 of total 7 patients on follow-up study, respectively).

One of our cases showed an unexpected finding where a distant anal canal nodular lesion was noted in PET/CT study in a case of rectosigmoid cancer away from the primary lesion not noticed in the MRI images. In the follow-up study, merging of the primary rectosigmoid and anal lesion was detected (Figs. 7, 8, 9).

Our results regarding18F-FDG PET/CT were remarkably higher than that of Yong Beom Cho et al. who found the overall accuracy rates for the T and N categories were 60% ($j=0.372$, $P=0.004$) and 71% ($j=0.097$, $P=0.549$), respectively. For the T category, two patients (7%) were overstaged and 10 patients (33%) were understaged; for the N category, one patient (4%) was overstaged and seven patients (25%) were understaged. 18F-FDG PET/CT predicted three of the four patients who showed a pathologic complete response after preoperative CCRT [14].

The study done by Yan Li et al. revealed that N staging using T2WIs, showed a sensitivity of 72% (8/11), specificity of 83% (10/12), and accuracy of 78% (18/23), while with a combined reading of PET and T2w images, the specificity could be increased to 91% (11/12) and the sensitivity was reduced to 63% (7/11) with the same accuracy of 78% (18/23) [15]. This agreed with our study that showed lower PET/CT sensitivity than MRI and comparable to the higher specificity of PET/CT in the assessment of N staging.

The overall high results in our study compared to the above-mentioned studies may be due to many limitations as the different timing of PET during neoadjuvant therapy, different chemotherapeutic agents and
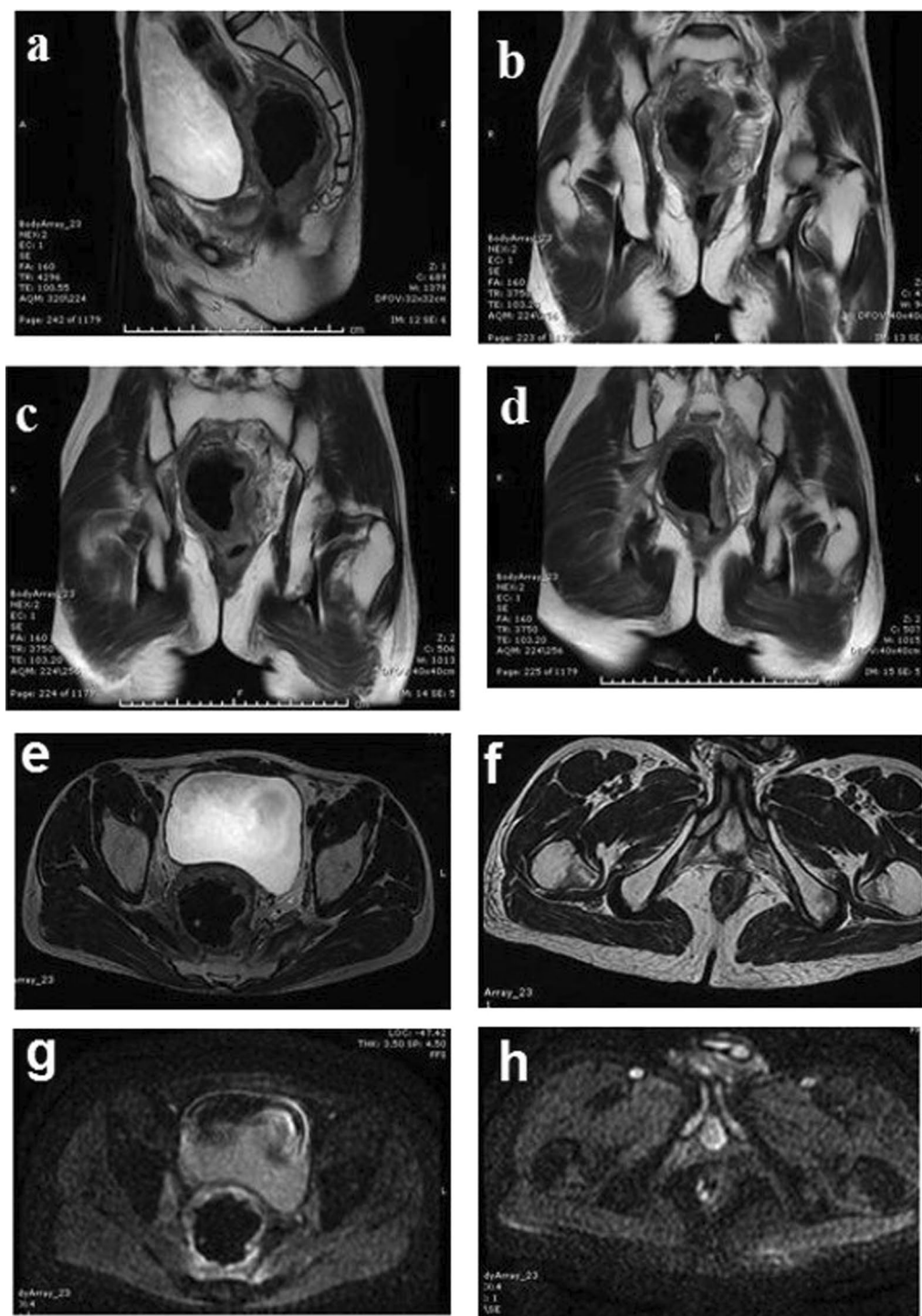
Fig. 7 a–h MRI study for a *30-year-old male with rectal adenocarcinoma of the rectum and received CRT*. **a–d** Sagittal, Coronal and **e–f** axial T2 WIs (g-h) DWIs revealed: Irregular circumferential mural thickening of the middle and lower rectum is seen reaching maximum thickness of 2.7 cm and extending for 7.6 cm in length, it start 3.8 cm from the anal verge, the mass lesion is seen infiltrating the right aspect of meso-rectal fascia, it elicits intermediate T2 SI with free diffusion. Subtle focus of hyperintense signal on DWIs was noticed at the end of anal canal but not reported as a significant finding
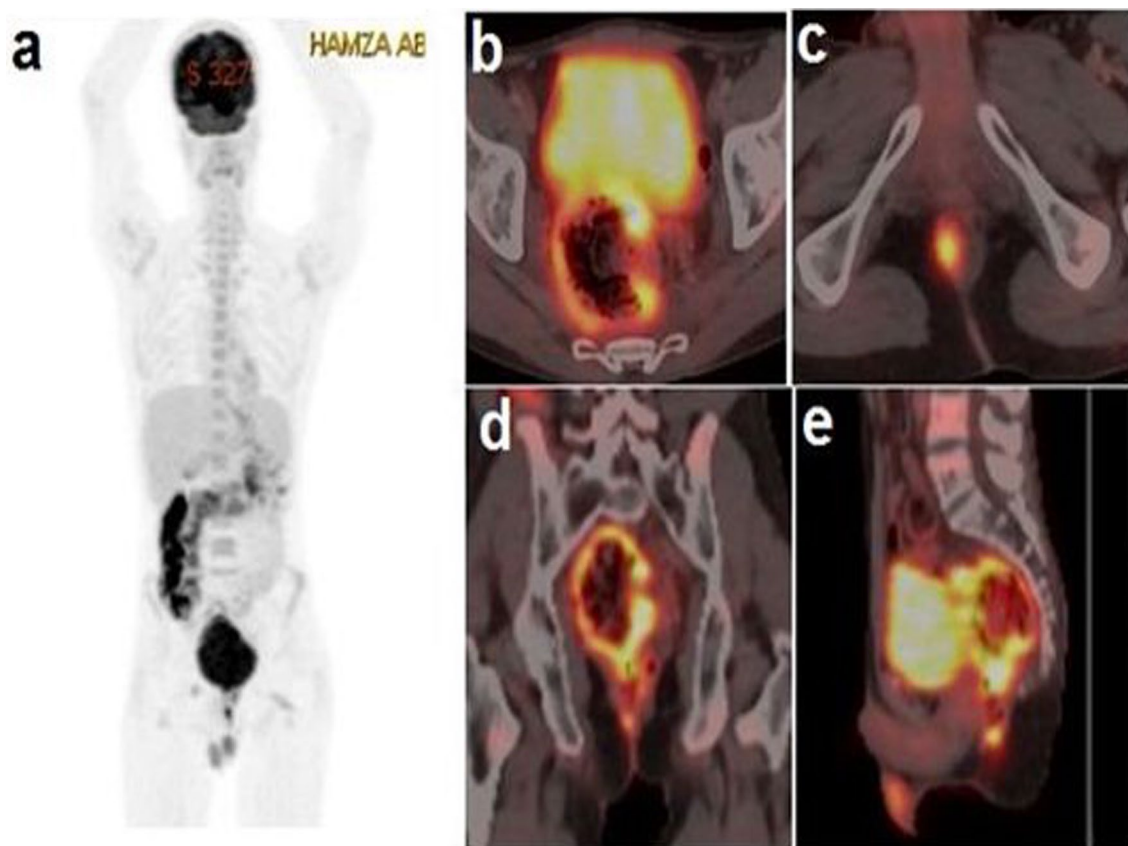
Fig. 8 **a–e** PET/CT study for the same patient in Fig. 7. **a** MIP and **b–e** fused PET/CT images revealed metabolically active (FDG avid) circumferential polypoidal mural thickening is seen involving the entire length of the rectum and rectosigmoid junction measuring about 2.2 cm at max thickness and 12 cm at max length with max SUV ~ 17.26, surrounded by fat smudging. Metabolically active (FDG avid) soft tissue nodule is seen at the right side of the anal canal measuring about 2.5 cm with max SUV ~ 9.79. Low grade metabolically active right inguinal lymph node is seen measuring about 1 cm with max SUV ~ 3.05 which increased to 3.6 on delayed scan

the dependency on serial imaging studies (which have subjective interpretation) rather than the non available correlation with histopathology (which is the golden end-point to avoid any interpretational Bias) in the evaluation of the local tumor response to treatment; as well as the missed baseline pretreatment study; consequently, our study may not be generalizable to the broader population.

Another limitation in our study is the heterogeneity of our sample including post CRT preoperative patients and postoperative patients. Reasons we did that; First, to avoid unrepresentative small sample size, second, because both share the same aim of our study which is the portraying of PET/CT and MRI roles in detection of

viable tumoral tissues (either for restaging or recurrence). However, we recommend future studies on each category of patients separately.

Summary

We had one false-negative patient on each study (MRI & PET/CT) who had undetected residual viable tumor. The reason behind the false-negative finding on MRI was due to > 75% fibrotic changes with hidden undetected viable cells, whereas the missed patient on PET/CT was reported as postoperative leaking anastomotic site on
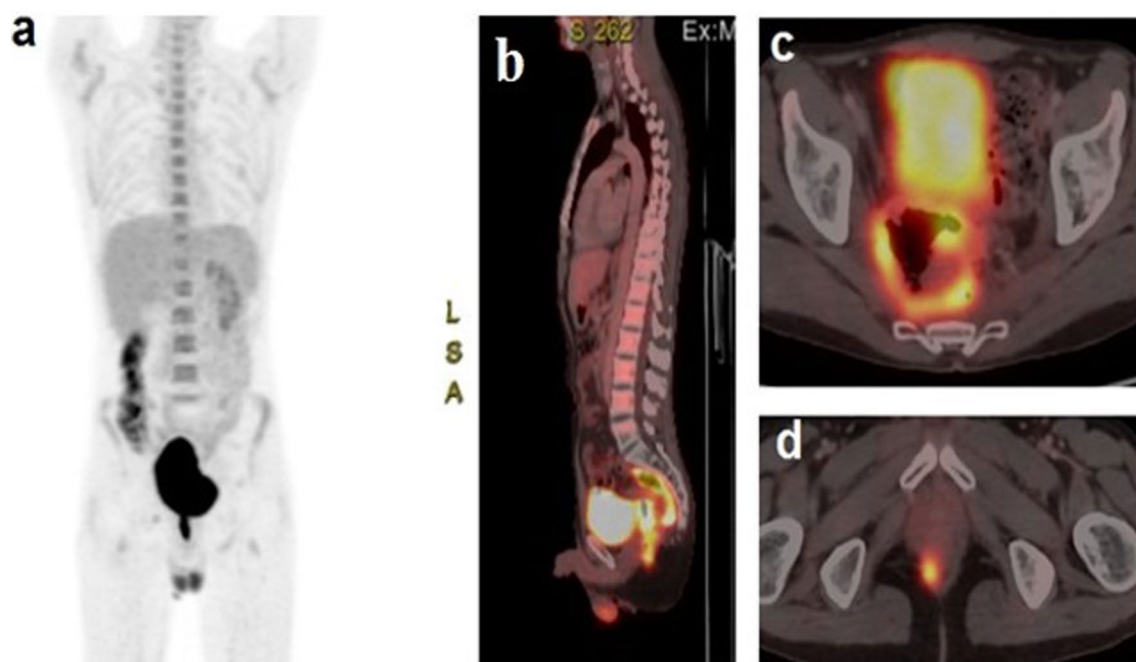
Fig. 9 **a–d** follow-up PET/CT study for the same patient in Fig. 7. **a** MIP and **b–d** fused PETCT images revealed progression in size and metabolic activity of the previously noted metabolically active (FDG avid) circumferential polypoidal mural thickening involving the entire length of the rectum and rectosigmoid junction measuring about 2.2 cm at max thickness and 13 cm at max length with max SUV R 22.8 (compared to 17.26 previously). The lesion now extends to the anal canal *blending* with the previously noted right sided anal soft tissue nodule. It is seen that intimately related to the posterior wall of the urinary bladder with no definite signs of invasion. Low grade metabolically active right inguinal lymph node is still seen unchanged measuring about 1 cm with max SUV R 3.07

PET/CT and showed focal areas of intermediate T2 signal on MRI denoting viable tumor.

Regarding N category; PET/CT showed two false-negative patients, who were missed due to the small size of the lesions, whereas MRI showed five false positive patients, depending on the criteria of > 5 mm in diameter and border irregularities, which was correlated to non FDG avid (metabolically inactive) remitted lesions on PET scan.

In our study, MRI was superior to PET/CT in detecting extension to nearby organs; owing to the more anatomical details of MRI regarding the involvement of mesorectal fascia and EMVI. PET/CT showed 6 false negative patients of 13 patients proved on follow-up study.

Almost total agreement of both MRI and PET/CT was noticed in evaluating post-therapy and postoperative complications (apart from on patient who showed long segment of diffuse FDG uptake on PET/CT while on MRI revealed diffuse post radiotherapy submucosal edema).

Conclusions

Using either PET/CT or MRI individually was not totally sufficient as several potentially confounding variables are present including post treatment fibrotic changes, post radiation inflammatory changes (which showed increased SUVmax), nodal assessment (depending on size and shape) and postoperative complications bias.

For locally advanced rectal cancer (pT3–4 N0 M0 or any T N1 M0), a multimodality strategy has been shown to be the best option to evaluate local disease process.

The combination between PET/CT and pelvic MR in the monitoring of post-therapy/postoperative cancer rectum is advisable to make use of the metabolic activity in the PET/CT as well as the add on value of the better morphological details in the MRI, that give higher sensitivity

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in the nodal evaluation, nearby organ invasion and post-operative/therapy complication.

Author contributions
MF contributed to the study conception and design, acquisition of data and drafting the manuscript. EN collected patients' data and follow-up of the cases, processed PET/CT findings at PET/CT workstation and shared in writing the manuscript. AY helped in the study design and revised the manuscript. All authors read and approved the final manuscript.

Availability of data and materials
Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Faculty of Medicine Banha University.

Consent for publication
All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests
The authors declare that they have no competing interests.

References
1. García-Figueiras R, Baleato-González S, Padhani AR, Luna-Alcalá A, Marhuenda A, Vilanova JC, Osorio-Vázquez I, Martínez-de-Alegría A, Gómez-Caamaño A (2018) Advanced imaging techniques in evaluation of colorectal cancer. Radiographics 38(3):740–765. https://doi.org/10.1148/rg.2018170044
2. Durán P, Jimenez F, Goic VP, Quintana de la Cruz R, Domínguez Ferreras E et al (2014) When colorectal surgery is performed: what to expect in CT evaluation? https://doi.org/10.1594/ecr2014/C-1665
3. Sasikumar A, Joy A (2017) 18F-FDG PET/CT: normal variants, artefacts, and pitfalls in colorectal cancer. In: Du Y (ed) PET/CT in Colorectal Cancer, Clinicians' Guides to Radionuclide Hybrid Imaging—PET/CT. Springer International Publishing Switzerland 2017. https://doi.org/10.1007/978-3-319-54837-1_5
4. Conradi L-C, Rödel C, Ghadimi M (2022) Rectal cancer: open questions in 2022 current standards of clinical practice and ongoing trials. Digestion 103(3):175–182. https://doi.org/10.1159/000522006
5. Kim DJ, Kim JH, Lim JS, Yu J-S, Chung J-J, Kim M-J, Kim KW (2010) Restaging of rectal cancer with MR imaging after concurrent chemotherapy and radiation therapy. Radiographics 30(2):503–516. https://doi.org/10.1148/rg.302095046
6. Kim CJ, Yeatman TJ, Coppola D, Trotti A, Williams B, Barthel JS, Dinwoodie W, Karl RC, Marcet J (2001) local excision of T2 and T3 rectal cancers after downstaging chemoradiation. Ann Surg 234(3):352–359. https://doi.org/10.1097/00000658-200109000-00009
7. Low G, Tho LM, Leen E, Wiebe E, Kakumanu S, McDonald AC, Poon FW (2008) The role of imaging in the pre-operative staging and post-operative follow-up of rectal cancer. Surgeon 6(4):222–231. https://doi.org/10.1016/s1479-666x(08)80032-7
8. Hong R (2012) 18F-Fluoro-2-deoxyglucose uptake on PET CT and glucose transporter 1 expression in colorectal adenocarcinoma. World J Gastroenterol 18(2):168. https://doi.org/10.3748/wjg.v18.i2.168
9. Lambregts DMJ, Boellaard TN, Beets-Tan RGH (2019) Response evaluation after neoadjuvant treatment for rectal cancer using modern MR imaging: a pictorial review. Insights Imaging. https://doi.org/10.1186/s13244-019-0706-x
10. Beets-Tan RGH, Lambregts DMJ, Maas M, Bipat S, Barbaro B, Curvo-Semedo L, Fenlon HM et al (2017) 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):1465–1475. https://doi.org/10.1007/s00330-017-5026-2
11. Zhuang Z, Zhang Y, Wei M, Yang X, Wang Z (2021) Magnetic resonance imaging evaluation of the accuracy of various lymph node staging criteria in rectal cancer: a systematic review and meta-analysis. Front Oncol. https://doi.org/10.3389/fonc.2021.709070
12. Murata H, Okamoto M, Takahashi T, Motegi M, Ogoshi K, Shoji H, Onishi M et al (2018) SUVmax-based parameters of FDG-PET/CT reliably predict pathologic complete response after preoperative hyperthermo-chemoradiotherapy in rectal cancer. Anticancer Res 38(10):5909–5916. https://doi.org/10.21873/anticanres.12935
13. Park J, Chang KJ, Seo YS, Byun BH, Choi JH, Moon H, Lim I, Kim BI, Choi CW, Lim SM (2014) Tumor SUVmax normalized to liver uptake on 18F-FDG PET/CT predicts the pathologic complete response after neoadjuvant chemoradiotherapy in locally advanced rectal cancer. Nucl Med Mol Imaging 48(4):295–302. https://doi.org/10.1007/s13139-014-0289-x
14. Cho YB, Ho- KC, Kim MJ, Choi JY, Park C-M, Kim B-T, Yun SJLH, Kim HC, Lee WY (2009) Accuracy of MRI and 18F-FDG PET/CT for restaging after preoperative concurrent chemoradiotherapy for rectal cancer. World J Surg 33(12):2688–2694. https://doi.org/10.1007/s00268-009-0248-3
15. Li Y, Mueller LI, Neuhaus JP, Bertram S, Schaarschmidt BM, Demircioglu A, Ludwig JM et al (2020) 18F-FDG PET/MR versus MR alone in whole-body primary staging and restaging of patients with rectal cancer: what is the benefit of PET? J Clin Med 9(10):3163. https://doi.org/10.3390/jcm9103163
16. Jia X, Zhang Y, Wang Y, Feng C, Shen D, Ye Y, Hong N (2019) MRI for restaging locally advanced rectal cancer: detailed analysis of discrepancies with the pathologic reference standard. Am J Roentgenol 213(5):1081–1090. https://doi.org/10.2214/ajr.19.21383

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