Accuracy of High Resolution Multidetector Computed Tomography in the Local Staging of Rectal Cancer

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Abstract

Background Magnetic resonance imaging (MRI) is the gold standard for local staging of rectal cancer. Advanced computed tomography (CT) machines are now capable of high-resolution images of rectal cancer and utilized for CT perfusion. The possibility of local staging of rectal cancer by CT needs to be explored.

Purpose The aim of the study is to evaluate accuracy of high-resolution CT for local rectal cancer staging.

Methods A high-resolution CT was performed for local staging of rectal cancer in our study group of 93 patients, where 64 underwent primary surgery and 29 underwent surgery post neoadjuvant chemoradiotherapy (NACRT).

Results In differentiating stages T2-and-less than T2 from T3–T4 rectal cancer, accuracy, sensitivity, specificity, and kappa score in overall patients were 91%, 87%, 94%, and 0.8; in primary surgery group were 89%, 76%, 94%, and 0.7; in NACRT group were 97%, 100%, 94%, and 0.9; in low rectal group were 94%, 89%, 97%, and 0.82, respectively.

Conclusion High resolution CT is an accurate tool for local staging of rectal cancer.

Keywords

- accuracy of CT staging
- rectal cancer
- mesorectal fascia
- histopathology

Introduction

Colorectal cancer is the second most common malignancy across the world. One-third of these cases are rectal cancers (RCs) with over 40% arising within 6 cm of the anal verge.¹ Radiologic imaging modalities have assumed vital importance in the staging of these patients as there has been a paradigm shift in the management of RC. The adoption of

the technique of total mesorectal excision as well as neoadjuvant chemoradiotherapy (NACRT) prior to surgery in advanced RC has improved the chances of survival by dropping local recurrence rates remarkably. Additionally, better survival of metastatic RC has been demonstrated by resection of liver and lung secondaries. Accurate local staging of RC and the relationship of the disease to the mesorectal fascia (MRF) or the T stage as well as identification of metastatic nodes

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(N stage), are the bases of choosing patients for primary surgery (PS) versus NACRT.

At the turn of the century, comparison of multidetector computed tomography (CT) and magnetic resonance imaging (MRI) by several authors showed conflicting reports with some papers suggesting CT to be superior to MRI in T1–T2 RC staging.² Others mention that due to its inherent low contrast resolution, CT lacks sufficient accuracy for distinction between the individual bowel wall layers.³ Consequently, MRI has evolved as the standard for local staging of RC and CT for distant staging. However, recent meta-analysis suggests an equal accuracy of CT as compared with MRI for local staging.⁴ Some suggest accuracy not only for high and mid RC but even for low RC with better T2-staging than MRI.⁵ CT perfusion, a recent application in RC is utilized to assess tumor biology and grading which affect survival as well as response to NACRT. The principle used is that due to a higher blood flow, blood volume, and vascular permeability the RC enhances differently from the normal mucosa.⁶ However, the guidelines for local RC staging continue to recommend MRI. Requirement of performing both MRI for local staging and CT for distant staging is expensive. Against this background we embarked on a prospective blinded observational study to evaluate whether CT could be utilized as a single modality to assess overall staging, local and distant for RC.

Materials and Methods

Patient Population

A prospective observational blinded study was performed from 2017 to 2019. The study group consisted of consecutive 93 patients, 69 men and 26 women with mean ages of 45 and 51 years, respectively. All patients were discussed at a multidisciplinary team meeting. Of these, 64 patients underwent PS, and 29 patients underwent surgery post NACRT. The NACRT course consisted of 5.5 weeks delivery of a dose of 45 to 50 Gray in fractions and a concomitant chemotherapy with capecitabine or 5-fluorouracil. Surgery was performed at an interval of 6 to 12 weeks after completion of chemoradiation. The number of patients with high, mid, and low RC were 22, 29, and 42, respectively. Informed consent from all patients and Institutional Ethics Committee approval were obtained.

High-Resolution CT Protocol

All patients underwent a mild bowel preparation with 1 L of polyethylene glycol the night before the examination. Oral or rectal positive contrast was not administered as this interferes with the evaluation of the mucosa.⁷ CT was performed on Aquilion One CT (Canon, Tokyo, Japan) in the 64-detector mode with intravenous contrast of 1 to 1.5 mL/kg iopromide (Ultravist 370; Schering, Berlin, Germany) at the rate of 4 mL/s. Scans were obtained during the arterial, early venous phase (EVP) of 40 seconds and a later venous phase (LVP) of 70 seconds delay after contrast injection with a 0.5-mm section thickness. The EVP gave the maximum contrast between the rectal wall and the RC. The arterial scan was included for vascular mapping needed for the resection of hepatic metastases as per institutional protocol. We improved the scan resolution of the EVP by reducing the field-of-view (FOV).^{8,9}

The combination of factors that yielded one significantly high-resolution CT phase were:

1. Inclusion of an EVP at 40 seconds from injection.
2. Sixty-four detector rows, 0.5-mm collimation with a pitch factor of 0.8.
3. Mild bowel cleansing 8 hours prior to scan.
4. 100 to 130 mL of 350 to 370 mg/mL of iodinated intravenous contrast at 4 mL/s.
5. Reducing the FOV to include up to the bony pelvic side walls laterally and from the sigmoid colon to the perineum craniocaudally, typically approximately 16 cm.

Image Analysis

The images were analyzed on a dedicated Vitrea workstation (Vital Images, Minnetonka, Minnesota, United States). Multiplanar reconstructions (MPRs) were performed and read by a radiologist with 26 years of experience and another with 7 years of experience with decision by consensus. Oblique reconstructions were used to obtain a “true axial plane” orthogonal to the anorectum (►Fig. 1A–D). Curvilinear reconstructions (CLR) were done with the centerline through the lumen of the rectum. These yielded true axial sections as well as a long axis straightened-out view bringing the anorectum in one two-dimensional (2D) image that can be rotated 360 degrees (►Fig. 1E, F). Depth of transmural invasion was categorized as ctT1, ctT2, ctT3, and ctT4, according to the AJCC TNM classification.

In the EVP, the rectal mucosa was seen as a brightly enhancing line as compared to the muscularis propria (MP). The submucosa was seen as a hypodense layer. The MP and internal sphincter (IS) are hypodense to the mucosa and isodense to the gluteal muscles. The RC enhanced as much as the mucosa or slightly more or less on this phase and was well differentiated from the MP (►Fig. 2). Mucinous tumors had fluid density and enhanced far less than the mucosa as well as the MP (►Fig. 3A, B).

The MRF was identified as a thin line around the mesorectum (►Fig. 2C). MRF was considered involved in all T4 RC (►Fig. 3C–F), and in T3 RC when the distance between the tumor margin and MRF was <1 mm.

Extramural vascular invasion (EMVI) was considered present when a slip of soft tissue was seen extending into the base of a draining vein which appeared unopacified distally (►Fig. 4A, B).

Nodes were considered metastatic when they were heterogeneous, more than 5 mm in short axis, with perinodal haziness and irregular contours (►Fig. 4C, D). Distant metastatic work-up was done by studying the rest of the abdomen. In case of hepatic secondaries, resectability analysis was done by vascular and segmental mapping with liver volumetry. CT findings were compared with histopathology (HP) as a reference standard. Pathology reporting was performed by senior pathologists with more than 10 years of experience.

Statistical Analysis

The sensitivity, specificity, accuracy, positive predictive value, negative predictive value of CT for RC in the PS and post NACRT groups were calculated. The kappa test of agreement was also performed between CT and HP.

Fig. 1 (A–D) Multiplanar post processing reconstructions through a low rectal cancer in a 54-year-old woman staged at T3c by CT and T3 by HP with R0 resection. A, B, C and D rows represent upper rectum, mid rectum, lower rectum, and anal canal levels, respectively. The letters S, C, and X represent sagittal, coronal, and axial sections through the above levels. The cross hair demonstrates how the true orthogonal plane is obtained through the rectum and anal canal. Placing the red line perpendicular to the lumen of the anorectum corrects for the angulation in the anteroposterior plane. Placing the blue line parallel to the length of the rectum corrects for the right to left obliquity. These maneuvers yield a true axial section at AX, BX, CX, and DX images in the panel. Curvilinear reconstruction in (E) shows the centerline (dotted yellow line) drawn through the lumen of the rectum and anal canal. Panel (F) shows the resultant CLR with the entire length of the rectum and anal canal. The upper and lower limits of the RC are marked by arrowheads. The three white dots represent the layers of the normal rectal wall just cranial to the RC. Medial dot—bright mucosa, middle dot—dark submucosa containing fibrofatty tissue, lateral dot—muscularis. CLR, curvilinear reconstruction; HP, histopathology; RC, rectal cancer.

Fig. 2 Panels (A, C) show subsequent axial images in the EVP through the mid rectum of a 63-year-old woman with a well-differentiated RC staged by CT and HP to T2. Panels (B, D) are diagrammatic representations of A and C, respectively. The mucosa is seen as a bright line drawn green on B and D. The submucosa is the dark zone just outside of the mucosa (small arrows in A and C). The muscularis propria is the muscle density layer contained within the two concentric blue lines in B and D. The RC is outlined by red in B and D and seen as a brightly enhancing thickening of the mucosa from 3 to 7 o'clock position, growing into the MP but not beyond it (arrowhead in C). The MRF is seen as a thin muscle density line around the mesorectum (notched arrows in C). Panels (E, F) show the anterior peritoneal reflection (arrowheads). EVP, early venous phase; HP, histopathology; MP, muscularis propria; MRF, mesorectal fascia; RC, rectal cancer.

Results

► **Table 1** lists the performance of high-resolution CT for RC staging.

T Stage

In differentiating stages T2-and-less T2 from T3–T4, the accuracy, sensitivity, specificity, and agreement Kappa score of CT overall were 91%, 87%, 94%, and 0.8 (excellent), respectively; in the PS group were 89%, 76%, 94%, and 0.7 (good), respectively (► **Table 2**); in NACRT group were 97%, 100%, 94%, and 0.9 (excellent), respectively (► **Table 3**); in low RC group were 89%, 97%, 94%, and 0.8 (excellent), respectively.

Node-Positive versus Node-Negative Stage

Node-positive versus node-negative accuracy, sensitivity, specificity, and agreement Kappa score in overall patients were 75%, 87%, 65%, and 0.5 (fair); in PS group were 72%, 93%, 54%, and 0.4 (fair) (► **Table 4**); in NACRT group were 83%, 75%, 88%, and 0.6 (fair) (► **Table 5**).

Circumferential Resection Margin Status

Circumferential resection margin (CRM) positivity accuracy, sensitivity, specificity, and agreement Kappa score in overall patients were 91%, 81%, 94%, and 0.8 (excellent agreement); in PS group were 91%, 90%, 88%, and 0.8 (excellent agreement); in NACRT group were 93%, 60%, 100%, sample

Fig. 3 Panel (A) is a coronal CLR in the EVP of a 43-year-old man with mucinous RC. The tumor is low density compared with the mucosa (marked by the arrow at the upper edge). It grows outward from the right wall (marked by white dots) to involve the levator ani. It also undermines the mucosa and grows beneath it displacing it toward the lumen (arrowhead). Panel (B) shows an oblique coronal planar reconstruction in the EVP of a mucinous low-density polyp marked within dots in a 56-year-old man staged at T1 by both CT and HP. (C, D) Post NACRT RC in a 46-year-old man with partial response staged at yctT4 and matching with HP. CLR in the EVP is rotated to show the inter-sphincteric planes on the right and left, respectively. Curved arrows on both show involvement of the levator ani muscles. Straight arrows reveal sparing of the puborectalis on the right and infiltration on the left. The anal verge is marked by a white dot in each and the tumor is seen extending into the internal sphincter, especially on the left. Panel (E) is axial image in EVP with arrow marking infiltration of the prostate anteriorly. Panel (F) Hematoxylin-eosin 4X HP section reveals the RC (arrowheads) infiltrating into the MP. CLR, curvilinear reconstruction; EVP, early venous phase; HP, histopathology; MP, muscularis propria; NACRT, neoadjuvant chemoradiotherapy; RC, rectal cancer.

too small for kappa, respectively. The small sample size also lowered the sensitivity here.

EMVI Status

EMVI positivity accuracy, sensitivity, specificity, and agreement Kappa score in overall patients were 96%, 94%, 96%, and 0.9 (excellent agreement); in PS group were 98%, 94%, 100%, and 0.9 (excellent agreement); in NACRT group were 90%, 100%, 89%, and sample was too small for kappa, respectively.

Discussion

Emergent Role of CT for Bowel Wall Imaging and Role of New Post Processing Tools

With advanced capability to perform submillimeter isotropic sections rapidly in various phases of the contrast, CT has emerged as an accurate modality to assess bowel wall. ^{10,11} In our study rectal wall layers are well visualized on CT (►Fig. 5 A–D). In the EVP, the MP and IS do not enhance improving the contrast between these and the RC. In LVP recommended thus far, the MP and IS enhance to become isodense to RC, posing a challenge in assessing depth of invasion (►Fig. 5E, F). Advanced workstation post-processing plays an important role in CT accuracy. With MPR the accuracy of CT staging for RC is higher (87–88%) as compared with only axial analysis (73–78%). ^{12,13} The rectum is a curvilinear structure. Reconstructions perpendicular to the long axis of the tumor are essential for accurate T-staging. This is feasible easily at CT oblique postprocessing.

CLR is used for detecting subtle wall abnormalities in the biliary tree and the complex periampullary region. ⁷ CLR allows for display of a hollow viscus on one 2D image and is the mainstay of coronary CT angiograms. ¹⁴ We use this tool with rotation of CLR along the centerline through the lumen of anorectum giving a good view of the wall and relations. Low RC can be aligned with the entire length of the anorectum in one 2D image giving a straightened-out panoramic view (►Fig. 6).

T Stage and CRM Involvement

►Table 6 provides a comparison of our study with various studies and meta-analysis on the accuracy of RC staging by CT, MRI, and ERUS. Li et al ⁴ in their meta-analysis of 89 studies found CT (sensitivity 88%, specificity 79%) to be equal to MRI (sensitivity 89%, specificity 76%) for T staging. Al-Sukhni et al in their meta-analysis of 21 studies found an 87% sensitivity and 75% specificity of MRI for T staging. ¹⁵ Our overall sensitivity of 87% matched and a specificity of 94% bettered that of MRI for differentiation of T2-and-less than T2 from T3–T4 RC. In our PS group, three out of 13 T2 were upstaged to T3a whereas, in two patients an erroneous sampling at HP may have caused a mismatch. T staging of some of the polyps presented difficulty in our study. One polyp (T stage on HP [pT]1) that was large, distended the rectum taking the wall close to the MRF (staged ctT3a) (Fig. 7A, B). Two polyps (pT2) located at acutely angulated segments were staged at ctT1. Polyps on straight segments of the rectum were accurately staged

Fig. 4 Coronal oblique planar reconstruction (A) and axial image (B) in the EVP of a 41-year-old woman with a poorly responding low RC post NACRT show a “rose thorn like” slip of enhancing tumor tissue rising into the adjacent vein representing EMVI in panel A (arrow) confirmed on HP. The distal part of the vein is collapsed and marked by small white dots. In comparison the veins without EMVI are well opacified distally (arrowhead in panel A). The leading edge of the enhancing bright tumor infiltrates the low-density internal sphincter (notched arrow in panel A) highlighting the usefulness of the EVP. Panel (B) shows the intact MP on the right within white dots whereas full thickness involvement on the left with minimal extension beyond staged to yctT3a which matched with HP. Axial panel (C) and coronal oblique panel (D) images through the mid rectal RC in late venous phase in two different patients reveal a heterogeneously enhancing metastatic node in panel A (arrow) and poorly enhancing necrotic node (arrow) of a mucinous RC (marked within dots) in panel B. EMVI, extramural vascular invasion; EVP, early venous phase; HP, histopathology; MP, muscularis propria; NACRT, neoadjuvant chemoradiotherapy; RC, rectal cancer.

Table 1 Performance of CT for staging of rectal cancer

CT staging of rectal cancer	Overall staging N = 93					Low rectal cancer staging N = 42				Primary surgery staging N = 64				Post NACRT staging N = 29			
	T1–2 vs. T3–4	N+ vs. N	CRM+	EMVI +	<T2 vs. T3–4	T1–2 vs. T3–4	N+ vs. N–	CRM+	EMVI +	<T2 vs. T3–4	N+ vs. N	CRM+	EMVI +	<T2 vs. T3–4	N+ vs. N	CRM+	EMVI +
Sensitivity	87	87	81	94	89	76	93	88	94	100	75	60	100	100	75	60	100
Specificity	94	65	94	96	97	94	54	91	100	94	88	100	89	94	88	100	89
PPV	87	67	82	88	94	81	63	79	100	93	82	100	25	93	82	100	25
NPV	94	87	94	99	94	92	90	95	98	100	83	92	100	100	83	92	100
Accuracy	91	75	91	96	94	89	72	90	98	97	83	93	90	97	83	93	90
Kappa score	0.8	0.5	0.8	0.9	0.82	0.7	0.4	0.8	0.9	0.9	0.6	DI	DI	0.9	0.6	DI	DI

Abbreviations: CRM+, positive circumferential resection margin; DI, data insufficient; EMVI, extramural venous invasion; NACRT, neoadjuvant chemoradiotherapy; NPV, negative predictive value; PPV, positive predictive value.

Note: All values are in percentages. N+ is N1 or N2 and N is N0 stage.

Table 2 Comparison of CT and histopathological T staging of rectal cancer patients who underwent primary surgery without NACRT

Primary T staging Total cases 64	ctT1	ctT2	ctT3	ctT4	Weighted kappa score of 0.785. Good agreement between HP and CT
pT1(4)	2	1	1	0	
pT2(13)	2	8	3 (T3a)	0	
pT3 (39)	0	3 (T3a)	37	0	
pT4(7)	0	0	0	7	

Abbreviation: HP, histopathology.

Note: pT1 to pT4 are histopathological staging. ctT1 to ctT4 are CT staging.

Agreement between HP and CT was good with a weighted Kappa score of 0.785

Table 3 Comparison of CT and histopathological T staging of rectal cancer patients who underwent surgery post NACRT

Post NACRT T staging Total cases 29	yctT0	yctT1	yctT2	yctT3	yctT4	Weighted kappa score of 0.9. Very good agreement between HP and CT
ypT0(5)	5	0	0	0	0	
ypT1(4)	1	2	1	0	0	
ypT2(5)	0	1	3	1 (T3a)	0	
ypT3(13)	0	0	0	13	0	
ypT4(2)	0	0	0	0	2	

Abbreviations: HP, histopathology; NACRT, neoadjuvant chemoradiotherapy.

Note: ypT1 to ypT4 are histopathological staging. yctT1 to yctT4 are CT staging.

Agreement between HP and CT was very good with a weighted Kappa score of 0.9.

Table 4 Comparison of CT and histopathological N staging of rectal cancer patients who underwent primary surgery without NACRT

Primary nodal staging. Total cases 64	ctN0	ctN1	ctN2	Weighted kappa score of 0.436. Moderate agreement between HP and CT
pN0 (35)	19	10	6	
pN1(14)	2	6	6	
pN2(15)	0	4	11	

Abbreviations: HP, histopathology; NACRT, neoadjuvant chemoradiotherapy.

Note: pN0 to pN2 are histopathological staging. ctN0 to ctN2 are CT staging; Agreement between HP and CT was moderate with a weighted Kappa score of 0.436.

Table 5 Comparison of CT and histopathological N staging of rectal cancer patients who underwent surgery post NACRT

Post NACRT nodal staging Total cases 29	ctN0	ctN1	ctN2	Weighted kappa score of 0.637. Good agreement between HP and CT
pN0(17)	15	1	1	
pN1(9)	2	7	0	
pN2(3)	1	0	2	

Abbreviations: HP, histopathology; NACRT, neoadjuvant chemoradiotherapy.

Note: pN0 to pN2 are histopathological staging. ctN0 to ctN2 are CT staging; Agreement between HP and CT was good with a weighted Kappa score of 0.637.

(Fig. 7C–E). Flor et al showed high accuracy of T staging by an apple-core deformity of the wall in stage T3–T4 tumors on CT colonography.¹⁶ This may hold merit in rectal polyps along acute curves. Wolberink et al, showed a mediocre performance of CT for assessing CRM involvement probably because of the lack of standardization of CT protocol and no MPR.¹⁷ Whereas, our protocol has yielded a 90% accuracy for a positive CRM in the PS and 93% in the NACRT groups.

Low Rectal Cancer T Stage

Vliegen et al found a reduced CT accuracy in low RC for MRF involvement along the anterior aspect without MPR.¹⁸ Shida et al,⁵ however, showed that CT accuracy (89%) surpassed MRI (71%) in low RC. In our study too, the accuracy of differentiating T2-and-less than T2 from T3–T4 was high at 94% in low RC (►Fig. 8A–C). Of the 18 cases at T2-and-less, one was over-staged to T3a. Of the 24 pT3–T4, only two were under-staged by CT (►Table 7). This high yield is attributed

Fig. 5 Axial images in the EVP of Stage T2 RC in two different patients marked within the white dots, on the left wall in panel (A) and right wall in panel (B). RC enhances more than the underlying MP and clearly stands out. Panels (C, D) are corresponding Hematoxylin-eosin 4X HP sections. Arrowheads in C mark the RC and dots mark the MP. In (D) stars mark the RC pushing into the MP (black dots). A tumor nest in the MP is marked by the arrowhead. Axial images in EVP (E) and LVP (F) in a 53-year-old woman with stage T2 low RC demonstrate the usefulness of the EVP with the RC (notched arrow) clearly defined and enhancing brighter than the MP (right angle arrow). Whereas in the LVP the MP enhances to become isodense with the RC and the two cannot be separately seen. The arrowheads mark a large draining vein. EVP, early venous phase; HP, histopathology; LVP, later venous phase; MP, muscularis propria; RC, rectal cancer.

to our high-resolution protocol providing a sharp contrast between the enhancing bright RC that invades the nonenhancing MP and IS (►Fig. 8E, F).

Post NACRT T-Stage

The accuracy of T-staging was higher in our study for post NACRT (97%) as compared with PS (89%). We assessed

Fig. 6 A series of rotations in a curved reconstruction through the lumen of the rectum shows the low RC (staged at T3 in both CT and HP) and its relation to the MP as well as the anal canal. A clockwise rotation beginning at (A) brings the rectum through left obliques at (A) and (B) into the coronal plane at panel (C). Involvement of the left Levator ani is seen at panels A and B (arrowheads). Further rotation brings right oblique planes at (D) and (E) and nearly sagittal at (F). No involvement of the vagina is seen (arrows in panels E and F mark the cervix) with a clear plane between the rectum and the vagina (arrowheads in panels E and F). A sharp margin is seen between the lower edge of the enhancing RC (curved arrow panel C) and the relatively nonenhancing muscular internal sphincter (dots in panel D) in the EVP. Dots in (A) mark the puborectalis muscles on either side. The tumor does not cross below this level. EVP, early venous phase; HP, histopathology; MP, muscularis propria; RC, rectal cancer.

viability by tumor enhancement. In complete response, we observed the normal three-layered appearance of the rectum restored post NACRT (►Fig. 9A, B). In some mucinous tumors the nonviable RC showed fluid density and no enhancement (►Fig. 9C–H). de Jong et al (46 studies) compared the accuracy of CT, MRI, and ERUS for response post NACRT. CT performed better than MRI with an accuracy for total response of 83% as compared with MRI of 75%.¹⁹ Restaging with diffusion-weighted imaging has shown to improve the mean sensitivity to 83.6% and specificity to 84.8%.²⁰

Nodal Staging

Nodal staging has low accuracy both on CT and MRI. Size criteria result in only a moderate accuracy. Some authors report lymph nodes with a diameter of 10 mm or more invariably malignant,³ whereas others found 74% of RC lymph nodes larger than 10 mm free of cancer and up to 50% of involved nodes smaller than 5 mm with 8% being less than 3 mm²¹ (►Fig. 10A, B). RC also causes an antigenic immune challenge to the draining lymph nodes which may result in nodal hyperplasia causing reactive enlargement of regional lymph nodes.²¹ The accuracy for node-positive status in our study was better in the NACRT group with 15 out of 17 node-negative cases correctly identified. The number of

total nodes post NACRT were also few in agreement with Koh et al.²²

Challenges in MRI Local Staging of RC

Although some studies have reported a high accuracy for MRI, these results have not been widely reproduced. The accuracy of MRI depends on the experience of the radiologist and is subject to significant inter- and intraobserver variability.²³ CT is easier to interpret and in one study, examiner's experience was found to have no substantial impact on the reproducibility of CT enterography in the assessment of patients with Crohn's disease.²⁴

Peritumoral desmoplastic stranding may give a spiculated appearance beyond the MP overstaging of T2 to T3.³ 3T MRI does not add any benefit.²⁵ In our study we observed that in the EVP fibrous tissue does not enhance and the desmoplastic spiculations remain hypodense to tumor thus improving differentiation of T2 from T3a (►Figs. 7C, D and 10C–E).

On MRI, appropriate angulation of the axial plane orthogonal to the tumor is inaccurate if the tumor is difficult to identify due to motion artifacts, small size, or intrinsic low contrast between tumor and rectal wall. Redundancy and tortuosity of the rectum can also yield oblique rather than true axial sections with blurring of the MP.²³ CT with its dynamic oblique and CLR capabilities can post-process the entire volume

Table 6 Comparison of various studies and meta-analysis on accuracy of rectal cancer staging by CT, MRI, and endorectal ultrasound. The last row is our study

Studies	No of patients	CT detect-or row 4/16/64/ mixed	CT bowel preparation	CT slice thickness	CT MPR	CT positive oral contrast used	CT per rectal air or saline	CT scan delay in seconds post injection	MRI machine details	Study type	Post NCRT patients included	Sensitivity	Specificity	Accuracy	T-staging
De Jong et al, 2016 Meta-analysis 46 studies Post NACRT	NA	NM	NM	NM	NM	NM	NM	NA	NM	Meta-analysis	Y	95 96 97	31 21 30	75 83 82 72 65 72	MRI CR CT CR ERUS CR MRI node + CT node + ERUS node +
Li et al, 2016. Meta-analysis 89 studies	NA	NM	NM	NM	NM	NM	NM	NM	NM	Meta-analysis	Y	89 88 89	76 79 80		MR T stage CT T Stage ERUS T stage
Shida et al, 2017 Pathology as reference Low rectal cancers	CT 45 MRI 34	64	Y	0.5 mm	Y	N	CO ₂	50	3T	Prospective blind	N	83 82 100 0	95 100 92 100	93 93 96 94 74 74	CT T1 CT T2 CT T3 MRI T1 MRI T2 MRI T3
Jan Scheele et al, 2018. N = 184	MRI 38 CT 141 EUS 63	NM	NM	NM	NM	NM	NM	NM	NM	Retrospective	N	89 66 76	38 40 63 45 58 62	66 58 70 61 55 57	MR T1/T2 vs. T3/T4 CT T1/T2 vs. T3/T4 ERUS T1/T2 vs. T3/T4 MRI node + CT node + ERUS node +
Al-Sukhni et al, 2012 Meta-analysis 21 studies												87 77 77	75 71 94		MRI T-stage MRI node + MRI CRM/ MRF +
Our study	CT 93	64 slices	Y	0.5 mm	Y	N	N	40 s	NA	Prospective blind	Y	87 87 81 94	94 65 94 96	91 75 91 96	CT T1/T2 vs. T3/T4 CT node + CT CRM/MRF + CT EMVI +

Abbreviations: CR, complete response; CRM +, circumferential resection margin involved; CT, computed tomography; ERUS, endorectal ultrasound; MPR, multiphase reconstruction; MRI, magnetic resonance imaging; N, no; NA, not available; NM, not mentioned; Node +, nodal involvement; Y, yes.

Fig. 7 Panels (A) axial and (B) sagittal images in the EVP of a 59-year-old man with a large rectal polyp arising from the anterior wall marked by arrows on panel B. This was wrongly staged to T3 at CT due to distension of the rectal lumen and bringing the rectal wall close to the MRF anteriorly (arrowhead panel A). The MP is stretched thin and seen only at places (arrow on panel A) making it difficult to assess. Curved coronal reconstruction (C) and axial (D) in the EVP of another 57-year-old man with a stage T2 polyp on both CT and HP arising from the right wall marked within white dots. The mucosa is seen separately (arrowhead in B) from the MP (straight arrow in B). The MP at the base of the polyp is infiltrated and shows similar enhancement as the polyp. Low density spiculations are seen just outside the MP (notched arrow in A and B). These represent desmoplasia and do not enhance in the EVP as much as the RC easing the differentiation of T2 from T3a lesions. Panel (E) Hematoxylin-eosin 4X HP section reveals the RC within black dots pushing into the inner circular layer of the MP marked by arrows. The arrowhead marks the outer edge of the outer longitudinal layer. EVP, early venous phase; HP, histopathology; MP, muscularis propria; MRF, mesorectal fascia; RC, rectal cancer.

dataset with ease, acquiring true axial images and rotating the rectum through a center line along its lumen to see all the walls and its surroundings in the long axis in one 2D image. Lymph nodes along the pelvic sidewall and superior rectal vessels may fall outside the FOV on MRI²³ but not CT.

Mucinous RCs pose a challenge at restaging by MRI as the mucin persists despite post NACRT.²⁶ We compared on CT the pre-NACRT presence of enhancing soft tissues interspersed within mucin for residual enhancement post NACRT which would mean lack of response (→ Fig. 9C, D).

Fig. 8 Low polypoid RC in a 55-year-old woman staged at T2 by both CT and HP. (A) Coronal reconstruction in the EVP. Enhancing tumor tissue is seen along the right side of the polyp at its base infiltrating the MP (arrow). (C) Curvilinear reconstruction in the EVP through the lumen of the anorectum rotated toward the left to open up the right inter-sphincteric plane. The polyp is marked within dots. The infiltration into the MP and not beyond with a clear inter-sphincteric plane (arrow) is better seen. The MP and internal sphincter (arrowheads) do not enhance in this phase sharply demarcating the lower edge of the tumor. In comparison panel (B) (coronal reconstruction in the LVP) shows poor distinction between the RC and MP/internal sphincter as these have begun to enhance in this phase. (D, E) Low RC in a 39-year-old man staged to T2 by both CT and HP. Panel (D) shows a coronal CLR in the EVP. (E) is the diagrammatic representation of D. The RC is outlined in white, Levator ani in green, puborectalis in pink, external sphincter in yellow, and the MP continuing caudally as IS in blue. The IS and MP do not enhance in this EVP with sharp demarcation between them and the RC. CLR, curvilinear reconstruction; EVP, early venous phase; HP, histopathology; LVP, later venous phase; MP, muscularis propria; RC, rectal cancer.

In an era where CT was not of sufficient temporal or spatial resolution to assess the layers of the bowel wall adequately, MRI had an advantage with its superior spatial resolution. It has established itself as the appropriate modality for local staging of RC. Despite this some authors acknowledged that CT could be a good alternative to MRI, when there is a restricted access to MRI, giving the advantage of local and distant staging in a single examination even with a 4 or 16 slice machine.¹⁷ Scheele et al found that CT had the lowest frequency of therapy relevant over-staging.²⁷ Maizlin et al demonstrated substantial agreement between readers in assessment of the tumor, MRF, and lymph nodes on

CT.²⁸ Their study was done on a 4 slice CT scanner, with positive oral contrast medium and no MPR evaluation.

Dar et al concluded that CT is a reliable radiological tool for local staging of RC with excellent accuracy rates for T and N staging.²⁹ Today CT perfusion and spectral CT applications provide extraordinary improvements in image quality.

It is known that inventions and radically novel technologies are the result of intentional combinations of two or more existing technologies through a process that involves interplay between experience and knowledge driven by need.³⁰ Radiology is not new to this idea of combinatorial evolution. PET-CT and PET-MRI are examples of such.

Table 7 Comparison of CT and histopathological T staging of overall low rectal cancer patients including those who had primary surgery and those who had surgery post NACRT

Total low rectal cancer <i>n</i> = 42	ctT0	ctT1	ctT2	ctT3	ctT4	Weighted kappa score of 0.82. Very good agreement between HP and CT
pT0(4)	3	1	0	0	0	
pT1(6)	1	3	1	1	0	
pT2(8)	0	1	7	0	0	
pT3(20)	0	1	1	18	0	
pT4(4)	0	0	0	0	4	

Abbreviations: HP, histopathology; NACRT, neoadjuvant chemoradiotherapy.

Note: pT0 to pT4 are histopathological staging. ctT0 to ctT4 are CT staging. Agreement between HP and CT was very good with a weighted Kappa score of 0.82.

Fig. 9 (A) Pre- and (B) post NACRT low RC EVP axial images in a 32-year-old man. The pre NACRT panel shows the RC sparing the MP at 10 o'clock position (arrowhead). However, at 3 o'clock position the RC infiltrates through the MP (arrow) and extends beyond 5 mm outward placing the stage at ctT3b. Post NACRT the rectal wall has returned nearly to its normal morphology and the submucosal dark layer is restored (arrow) with mild distortion of the mucosal line. This was staged at yctT1 which matched with HP. (C) Coronal planar reconstruction and (D) axial image through a post NACRT mucinous low RC in a 62-year-old man. There is total necrosis of the RC (dots in panel D) with no discernible enhancement. The normal mucosa and wall at the upper and lower edges of the tumor are marked by arrows. A necrotic node is seen on the left (arrowhead). This was staged at T0N0 and matched HP. (E) Axial and (F) coronal CLR images in the EVP prior to NACRT and (G, H) post NACRT of a 33-year-old man with signet ring cell adenocarcinoma. (E) shows a ctT4b concentric stenosing type of tumor infiltrating the prostate with an enhancing advancing edge (arrow). Post NACRT (G) shows no enhancement in this region with only low-density necrosis. The rectal wall margin is seen away from the MRF (arrowhead) and this was restaged to yctT3c. HP revealed CRM negative with a clearance of 0.2 mm and matched that of CT. Panel (F) shows an enhancing EMVI (arrow) pre NACRT. This shows necrosis in post NACRT (H) along with significant necrosis and ulceration (arrowhead) within the tumor. The lower edge of the tumor was seen well below the level of the puborectalis (arrowhead in panel F). The anal verge is marked by three dots. The APR specimen revealed tumor at 1.7 cm from the distal resection margin. APR, abdominoperineal resection; CLR, curvilinear reconstruction; CRM, circumferential resection margin; EVP, early venous phase; HP, histopathology; MP, muscularis propria; MRF, mesorectal fascia; NACRT, neoadjuvant chemoradiotherapy; RC, rectal cancer.

Likewise, CT and MRI can be utilized in a combinatorial manner to yield higher accuracy and better outcomes for RC patients.

Our study proves that high-resolution, contrast-enhanced, thin section CT performed with a small FOV in the EVP yields

high contrast between the RC and the various layers of rectal wall and is an accurate tool for local staging of RC.

The limitation of our study is the small number of patients especially in the post NACRT group. Further, large volume studies are required to validate our findings.

Fig. 10 Axial images in the LVP of two patients. Panel (A) shows nodes larger than 5 mm considered positive on CT (arrows). All of these were negative on HP with an N0 status. Panel (B) shows nodes less than 5 mm considered negative on CT (arrows). All of these were positive on HP. (C) Pre and (D) post NACRT axial images in the EVP of a 67-year-old man. A bulky concentric RC staged at T3c on CT is seen in (C) with involvement of the MRF anteriorly (arrow) as well as posteriorly. Post NACRT the anterior tumor margin has dropped away from the MRF leaving behind a nonenhancing tissue representing fibrosis. Residual enhancing tumor persists from 10 to 4 o'clock in the MP and minimally beyond it (yctT3a correlating with HP). In the rest of the posterior wall the MP has returned to the normal low enhancement suggesting absence of viable tumor here. Panel (E) is an axial section in the EVP of another 59-year-old man with a mid RC accurately staged at T2 by CT. Desmoplastic low-density spicules (straight arrows) are clearly differentiable from the enhancing tumor confined to the MP. Curved arrows mark the overhanging lateral margins of the RC in the lumen. EVP, early venous phase; HP, histopathology; LVP, later venous phase; MP, muscularis propria; MRF, mesorectal fascia; NACRT, neoadjuvant chemoradiotherapy; RC, rectal cancer.

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Conflict of Interest

None declared.

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