ORIGINAL CONTRIBUTION

Magnetic Resonance Texture Analysis in Identifying Complete Pathological Response to Neoadjuvant Treatment in Locally Advanced Rectal Cancer

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BACKGROUND: A certain proportion of patients with locally advanced rectal cancer experience complete response after undergoing neoadjuvant chemoradiotherapy. These patients might be suitable for a conservative "watch and wait" approach, avoiding high-morbidity surgery. Texture analysis is a new modality that can assess heterogeneity in medical images by statistically analyzing gray-level intensities on a pixel-by-pixel basis. This study hypothesizes that texture analysis of magnetic resonance images can identify patients with a complete response.

OBJECTIVE: This study aims to determine whether texture analysis of magnetic resonance images as a quantitative imaging biomarker can accurately identify patients with complete response.

DESIGN: This is a retrospective diagnostic accuracy study.

SETTINGS: This study was conducted at Colchester General Hospital, January 2003 to 2014.

PATIENTS: All patients diagnosed with locally advanced rectal cancer who underwent long-course chemoradiotherapy had a posttreatment magnetic resonance scan and underwent surgery are included.

INTERVENTION: Texture analysis was extracted from T2-weighted magnetic resonance images of the rectal cancer.

MAIN OUTCOME MEASURES: Textural features that are able to identify complete responders were identified by a Mann-Whitney *U* test. Their diagnostic accuracy in identifying complete responders was determined by the area under the receiver operator characteristics curve. Cutoff values were determined by the Youden index. Pathology was the standard of reference.

RESULTS: One hundred fourteen patients with first posttreatment MRI scans (6.2 weeks after completion of neoadjuvant treatment) were included. Sixty-eight patients had a second posttreatment scan (10.4 weeks). With no filtration, mean ($p = 0.033$), SD ($p = 0.048$), entropy ($p = 0.007$), and skewness ($p = 0.000$) from first posttreatment scans, and SD ($p = 0.042$), entropy ($p = 0.014$), mean of positive pixels ($p = 0.032$), and skewness ($p = 0.000$) from second posttreatment scans were all able to identify complete response. Area under the curve ranged from 0.750 to 0.88.

LIMITATIONS: Texture analysis of MRI is a new modality; therefore, further studies are necessary to standardize the methodology of extraction of texture features, timing of scans, and acquisition parameters.

CONCLUSIONS: Texture analysis of MRI is a potentially significant imaging biomarker that can accurately identify patients who have experienced complete response and might be suitable for a nonsurgical approach. (Cinicaltrials.gov:NCT02439086). See **Video Abstract** at http://links.lww.com/DCR/A760.

KEY WORDS: Complete response; Locally advanced rectal cancer; Magnetic resonance imaging; Neoadjuvant chemoradiotherapy; Texture analysis.

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Management of locally advanced rectal cancer (LARC) with curative intent involves neoadjuvant chemoradiotherapy (NCRT) followed by surgical resection of the rectum. Neoadjuvant treatment is offered to downstage the tumor, improve operability, and clear the surgical resection margins.[1] Approximately 20% of patients who undergo neoadjuvant therapy experience complete response (CR), with no cancer cells left in the irradiated rectum. Multiple studies have shown that patients who experience CR live longer with a better quality of life.[2,3] It is therefore argued that those patients are exposed unnecessarily to surgical resection of the rectum, with high morbidity and mortality.

However, there is currently no reliable accurate modality that can preoperatively identify those patients who have experienced CR after NCRT, because standard morphological imaging in the form of MRI or endorectal ultrasound has shown to suffer suboptimal accuracies in assessing the response to treatment[4] and specifically in identifying patients with CR. This is because of the failure of morphological imaging in differentiating posttreatment edema and fibrosis from remnant tumor mass. Therefore, functional imaging and quantitative imaging biomarkers are being assessed as potential adjunct modalities for assessing response to treatment.

Malignant tumors exhibit higher extracellular, intracellular, and genetic heterogeneity.[5] This is because of the variations in cellular proliferation, necrosis, hemorrhagic and myxoid changes in the extracellular matrix, and angiogenesis. Tumor biopsy specimens, in addition to being invasive, reveal only a minority of these variations within the lesion.[6] Histopathological assessment of the resected lesion as a whole can only be done postoperatively. It has therefore become essential to obtain information on tumor heterogeneity from noninvasive medical imaging.

Texture analysis is a quantitative imaging biomarker that assesses tumor heterogeneity by measuring the distribution of gray-scale intensities on a pixel-by-pixel basis. It provides a measure of uniformity and coarseness within the lesion from medical images, which aid in identifying underlying patterns and pathologies.[7] The statistical method of texture analysis studies the histogram of distribution of different gray-level intensities as a function of the number of pixels bearing that intensity, which is normally distributed. Texture parameters that are derived from the normogram distribution and their implication are summarized in Table 1.

Texture analysis has been shown to be an effective modality in identifying pathologies in breast, nasopharyngeal, and brain cancers.[8–10] It has been shown to be effective in discriminating benign from cancerous nasopharyngeal lesions, in classifying soft tissue tumors, and in monitoring response to treatments in breast and esophageal cancers. It has also been shown to exhibit a prognostic potential in predicting survival in patients with colorectal cancer.[11]

This study aims to determine whether MRI texture analysis (MRTA) as a quantitative imaging biomarker can accurately identify patients with CR. Those patients can then avoid exposure to a high-risk surgical procedure and adhere to a "watch and wait" protocol instead.

MATERIALS AND METHODS

Patients with suspected rectal cancer normally undergo a MRI scan before being discussed at a multidisciplinary meeting. Those staged as having locally advanced disease are normally offered a 5-week course of NCRT. Tumors with threatened resection margins, defined as a tumor closer than 1 mm to the mesorectum, are considered LARC, and are also offered NCRT. Patients then undergo a restaging MRI scan 6 weeks after the completion of treatment. Surgery is offered 4 weeks after restaging.

Eligibility Criteria

All patients diagnosed with locally advanced rectal adenocarcinomas between January 2003 and July 2014 in Colchester General Hospital, who underwent neoadjuvant treatment and had undergone at least 1 posttreatment MRI scan, were included.

Patients who did not receive long-course NCRT or who did not have an MRI after treatment were excluded. Patients who had a local excision procedure in the form of endoscopic mucosal resection were also excluded because the histopathological assessment failed to provide tumor regression grading or lymphatic assessment. Mucinous tumors or those that underwent mucinous degradation of their rectal adenocarcinomas were excluded from the analysis because mucinous cancers represent a separate entity pathologically. Also, the pools of high-intensity mucin rendered the texture analysis futile. The full protocol can be accessed on CinicalTrials.gov: NCT02439086.

Neoadjuvant Treatment

Established local protocol states that patients diagnosed with LARC are offered long-course chemoradiotherapy consisting of 45 to 50.4 Gy in 25 to 28 fractions over 5 weeks, with concomitant chemotherapy consisting of 240 $mg \cdot m^{-2} \cdot day^{-1}$ oral Tegafur-uracil on days 1 to 28, given with leucovorin 90 mg/day.

MRI Protocol

Our institution protocol states that a posttreatment restaging MRI scan is performed 6 weeks after completion of the neoadjuvant treatment. For research purposes, a subgroup of patients underwent a second posttreatment MRI 4 weeks later. Imaging protocol included an initial localizing scan followed by a sagittal T2-weighted fast spin-echo (FSE) sequence scan. An axial T2-weighted FSE was used to image the whole pelvis from the iliac crest to the

TABLE 1. Texture parameters derived from the normogram distribution of gray-level intensities, their definition, and implication

Parameter	*Definition*	*Implication*
Mean	The average intensities of pixels within a ROI.	Higher mean suggests a whiter image.
SD	A measure of dispersion from the average.	A low SD means that distribution of intensities is close to the mean. A high SD means that intensities are spread out among a large range of values.
Skewness	A measure of the asymmetry of the histogram.	Positive skewness: indicates that the right tail of the histogram is longer than the left side. Negative skewness: indicates that the left tail of the histogram is longer than the right side. A zero value means the values are evenly distributed on either side of the mean. (normal distribution)
Kurtosis	A measure of the peakedness (or flatness) of the histogram.	Positive kurtosis: distribution is more peaked than the normal distribution. Negative kurtosis: distribution is flatter than the normal distribution. Value of 3 is normal distribution.
Entropy	Measures disorder in the distribution of intensities.	Higher values mean more chaos. Lower values mean more homogeneity.

ROI = region of interest.

symphysis pubis to identify the pelvic side wall and nodal disease. An oblique axial T2-weighted FSE high-resolution sequence was performed with slices positioned perpendicular to the long axis of the rectum to enable accurate tumor staging. Finally, an oblique coronal T2-weighted FSE high-resolution sequence was performed in patients with a low rectal tumor. The slices were positioned along the long axis of the anal canal to show the relationship of the levator ani muscles to the tumor to demonstrate the degree of margin for resection. All sequences used a matrix of 256/256. Parameters for the scans are summarized in Table 2.

Two radiologists (D.B. and A.M.) blinded to clinical outcomes, pathological outcomes, and textural features, staged all pretreatment and posttreatment MRI scans. They had access to previous MRI staging and reports, however. Tumor regression grades on posttreatment MRI scans (mrTRG) were assessed according to the technique devised by the MERCURY study group,[12] which corresponds to the pathological tumor regression grade (TRG) devised by Dworak et al[13] summarized in Table 3. Note that the numbering of mrTRG and pathological TRG has been modified to match each other.

Histopathological Assessment

Histopathological assessment of resected specimens provides the standard of reference against which MRI staging was compared. The in-house pathologist at our institution restaged all resected specimens for this study blinded to radiological staging, texture analysis, and clinical outcomes. Histopathological reports contained the standard data set of histopathology results such as T and N stages. Information on the differentiation and whether the circumferential resection margin is involved or threatened is also reported. The TRG was assessed as developed by Dworak et al.[13]

MRI Texture Analysis

The MRTA process includes first identifying the axial slice on the T2-weighted MRIs that traverse the midsection of the tumor with the largest cross-sectional area. Choosing the MRI slice was performed under the supervision of a GI radiology specialist with 7 years' experience (A.A.). The region of interest (ROI) is then manually drawn to enclose the entirety of the cross section through the tumor. The ROI was drawn under the supervision of an imaging scientist (B.G.) with 9 years' experience in texture analysis. The ROI included the medium-intensity tumor tissue, with the low-intensity bowel lumen and muscularis propria excluded from the ROI. The MRTA of the selected ROIs was performed by using proprietary commercially available TexRAD research software (version 3.3, TexRAD Ltd www.texrad.com, part of Feedback Plc, Cambridge, UK). Figure 1 shows an example of a ROI drawn enclosing an ulcerating rectal cancer on the MRTA software (TexRAD). To validate this process of choosing the widest cross-sectional axial slice

TABLE 2. Parameters for the sagittal, axial, and oblique MRI scans

Parameter	*Sagittal sequence*	*Axial sequence*	*Oblique axial sequence*	*Oblique coronal sequence (low rectal)*
Recovery time (TR)	5020	3420	5200	5000
Echo time (TE)	89	85	95	93
Field of view (FOV)	26/26	40/40	20/20	20/20
Number of excitations (NEX)	4	2	6	6
Slice thickness/gap	4/1	5/1	3/0.3	3/0.3
Number of slices	19	30	Variable (tumor size)	Variable (tumor size)

TABLE 3. Tumor regression grade and corresponding description as assessed by MRI (mrTRG) and by histopathology (TRG)

TRG	*mrTRG*	*Description*
TRG 1	mrTRG1	No signs of regression/similar appearance to pretreatment
TRG 2	mrTRG2	Dominant tumor mass/signal intensity, with apparent fibrosis, chronic inflammation, and/or vasculopathy
TRG 3	mrTRG3	Dominant fibrotic changes and signal intensity, with substantial tumor load
TRG 4	mrTRG4	Few tumor cells remaining, with substantial fibrosis/low signal intensity
TRG 5	mrTRG5	Complete response, no tumor cells/ absence of tumor signal.

TRG = tumor regression grade.

through the midsection of the tumor, drawing the ROI, and extracting the textural features, interrater and intrarater variability was assessed by measuring intraclass correlation coefficient. The above process was piloted on 20 patients by 2 separate blinded researchers, 1 month apart. The results showed that interrater and intrarater variability were minimal, and that there is high concordance between readings with an intraclass correlation coefficient value of 0.959 (95% CI, 0.939–0.973) and 0.922 (0.886–0.947).

Extracting textural features first involves an image filtration step, where a Laplacian of gaussian band-pass filter is used. This step extracts and enhances objects/features corresponding to a specific spatial scale filter (SSF), which ranges from SSF = 2 mm (fine) to SSF = 6mm (coarse) in radius, with SSF = 3 to 5 mm in radius corresponding to medium

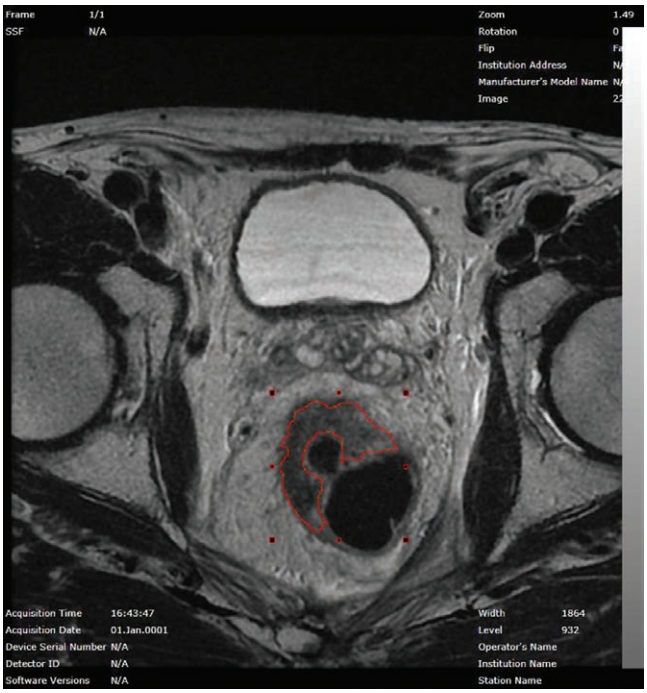

FIGURE 1. Region of interest (in red) drawn around an ulcerating rectal cancer on the texture analysis software (TexRAD).

texture coarseness. Each SSF value can be considered as the width at which structures in the image will be highlighted and enhanced, whereas structures less than this width will be blurred. The second step comprises texture quantification using statistically based histogram analysis, which results in the parameters summarized in Table 1. Textural parameters from nonfiltered ROIs were also extracted. Textural features were extracted by a researcher blinded to radiological staging, pathological staging, and survival outcomes.

Statistical Analysis

Categorical variables extracted from MRI scans included tumor radiological T stage, N stage, extramural venous invasion status, and circumferential resection margin status. Tumor regression grade (mrTRG) is also extracted on posttreatment scans. Pathological T staging, N staging, and pathological TRG are also obtained as categorical variables; they are considered the reference standard; and MRTA metrics are obtained as continuous variables.

All patients were categorized by their pathological response into CR, comprising TRG 5, and non-CR, comprising TRG 1 to TRG 4. The ability of the MRTA parameters with no filtration and at each individual SSF value in differentiating between CR and non-CR was assessed by using the Mann-Whitney *U* test. The diagnostic accuracy of MRTA parameters (which showed statistical significance on Mann-Whitney *U* test) in identifying CR was then assessed using receiver operating characteristic (ROC) analysis where the area under the ROC curve (AUC), along with the sensitivity and specificity, which were determined at the optimal cutoff. The optimal cutoff value was identified using the Youden index.[14]

RESULTS

One hundred fourteen patients were identified who had a diagnosis of LARC and underwent NCRT. All 114 patients underwent a first posttreatment MRI scan (designated MRI2) on average 6.2 weeks after completion of NCRT (median, 6.1; range, 3.0–11.7). A subset of 68 patients underwent a second posttreatment scan (designated MRI3) on average 10.4 weeks after completion of NCRT (median, 10.4; range, 4.0–15.1). Surgery was performed on average 13.7 weeks after completion of NCRT.

A subset of 9 patients did not proceed to surgery because 5 were diagnosed with CR and joined a nonoperative approach, and 4 were found to be inoperable at surgery. Those were excluded from any further analyses because there are no pathological results available. Overall, pathological CR was found in 24 patients (21.05%).

Identifying Complete Responders

Textural Parameters With No Filtration

When analyzing the textural features without applying any filtration, the independent Mann-Whitney *U* test showed

TABLE 4. MRTA parameters derived from first and second posttreatment scans in identifying CR with no filtration

MRTA parameters	CR mean ± SD	Non-CR mean ± SD	p value
First posttreatment scan (MRI2)			
Mean	–73.19 ± 11.76	–5.05 ± 19.95	**0.033**
SD	222.06 ± 8.18	191.14 ± 16.14	**0.048**
Entropy	6.09 ± 0.03	5.91 ± 0.06	**0.007**
MPP	194.40 ± 7.17	177.50 ± 15.00	0.189
Skewness	0.28 ± 0.02	0.04 ± 0.05	**0.000**
Kurtosis	0.49 ± 0.06	0.38 ± 0.11	0.963
Second posttreatment scan (MRI3)			
Mean	–68.50 ± 16.12	–52.68 ± 30.85	0.769
SD	244.50 ± 11.84	219.14 ± 26.86	**0.042**
Entropy	6.23 ± 0.04	6.01 ± 0.10	**0.014**
MPP	214.05 ± 10.07	186.48 ± 23.78	**0.032**
Skewness	0.27 ± 0.03	0.01 ± 0.06	**0.000**
Kurtosis	0.25 ± 0.06	0.05 ± 0.08	0.449

Statistically significant parameters are in bold.
CR = complete response; MPP = mean of positive pixels; MRTA = MRI texture analysis.

TABLE 5. Mean and SD values of skewness extracted from first and second posttreatment scans at different SSF values

MRTA parameters	CR (mean ± SD)	Non-CR (mean ± SD)	p value
First posttreatment scan (MRI2)			
Skewness			
SSF 2	0.113 ± 0.093	0.125 ± 0.047	0.832
SSF 3	0.017 ± 0.118	0.177 ± 0.047	0.055
SSF 4	**–0.121 ± 0.131**	**0.240 ± 0.047**	**0.007**
SSF 5	**0.136 ± 0.147**	**0.271 ± 0.049**	**0.008**
SSF 6	**0.058 ± 0.159**	**0.278 ± 0.050**	**0.036**
Second posttreatment scan (MRI3)			
Skewness			
SSF 2	–0.051 ± 0.133	0.113 ± 0.072	0.309
SSF 3	**–0.195 ± 0.143**	**0.169 ± 0.06**	**0.016**
SSF 4	**–0.135 ± 0.157**	**0.223 ± 0.049**	**0.014**
SSF 5	0.039 ± 0.152	0.249 ± 0.049	0.066
SSF 6	0.053 ± 0.124	0.281 ± 0.062	0.216

Statistically significant parameters are in bold.
CR = complete response; SSF = spatial scale filter in mm; MRTA = MRI texture analysis.

that textural features extracted from the first posttreatment MRI scans performed at an average of 6.2 weeks after completion of NCRT, namely mean, SD, entropy, and skewness, were all statistically able to identify complete responders. Textural parameters derived from the second posttreatment MRI scans, performed on an average of 10.4 weeks after completion of NCRT, were also significantly able to identify patients with CR. Standard deviation, entropy, skewness, and mean of positive pixels were all able to significantly identify CR. Table 4 summarizes the MRTA parameters extracted from the first and second posttreatment scans and their *p* values derived from the Mann-Whitney *U* test.

Textural Parameters With Filtration

Independent Mann-Whitney *U* test showed that only skewness of the textural features extracted from the first posttreatment MRI scans was significantly able to identify complete responders on SSF sizes of 4 mm, 5 mm, and 6 mm, with a *p* value of 0.007, 0.008, and 0.036.

Also from the second posttreatment MRI scans, skewness at SSF values 3 mm and 4 mm were significantly able to identify patients with CR with *p* values of 0.016 and 0.014. Table 5 shows the means and SD of skewness at different SSF values in identifying CR. *p* values were derived from the Mann-Whitney *U* test. Figure 2 shows the box and whiskers plots of the significant skewness values in Table 5.

ROC Analysis

Figure 3A and B shows the ROC curve for the above significant results. All parameters are plotted on the same curve, with the exception of skewness. This separation was necessary because the value of skewness seems to be inversely related to sensitivity, ie, higher skewness value is associated with CR; whereas, for the remaining parameters, higher values are associated with poor responders.

Accuracy of MRTA parameters ranged from 59.4% for skewness derived from the second posttreatment scan on a medium coarseness filtration (SSF value of 4 mm), to 88% from entropy derived from the second posttreatment scan without filtration. Table 6 summarizes the significant parameters, the AUC, their *p* values, and the optimal cutoff in identifying CR calculated by the Youden indices.

DISCUSSION

This study aimed to assess whether textural features derived by statistical methods from pre- and posttreatment MRI scans are able to identify patients with CR. This study showed that textural features extracted from the first and second posttreatment MRI scans performed at an average of 6.1 weeks and 10.4 weeks were significantly able to identify those with a CR. The AUC from the ROC analyses showed a maximum accuracy of 88% with entropy derived from the histogram of the second posttreatment scans.

For comparative purposes, the accuracy of MRI in staging tumor regression grade (mrTRG) was calculated from our study population for both time intervals. The first posttreatment MRI scan correctly staged 86 of 114 staged patients, providing an accuracy of 75.4%; whereas the second posttreatment MRI scan correctly staged 53 of 63 staged patients, providing an overall accuracy of 77.9%. In identifying CR, the second posttreatment MRI correctly categorized 7 of the 13 pathological CRs, and

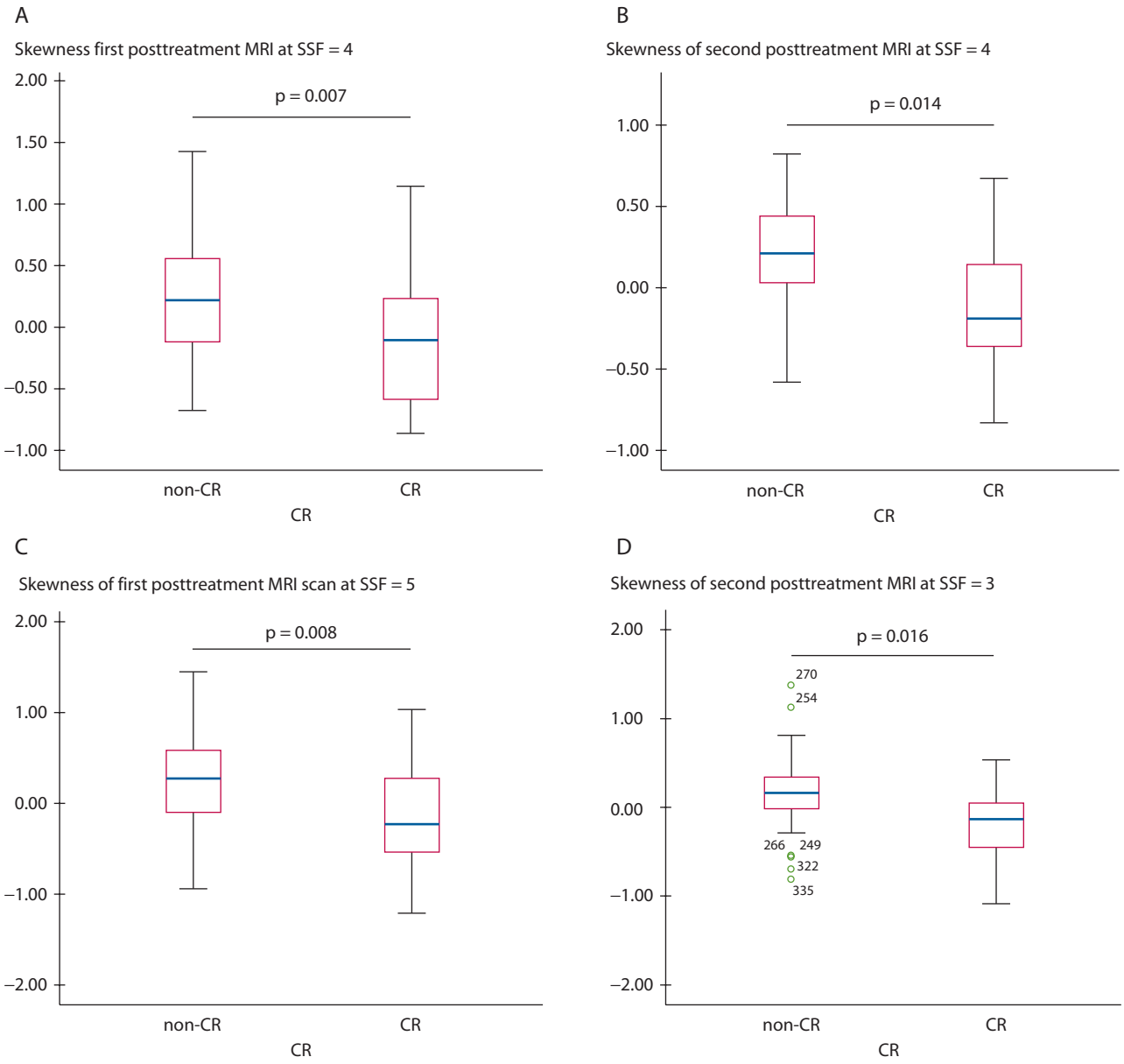

FIGURE 2. A, Skewness extracted from first posttreatment MRI at SSF 4. B, Skewness extracted from second posttreatment MRI at SSF 4. C, Skewness extracted from first posttreatment MRI at SSF 5. D, Skewness extracted from second posttreatment MRI at SSF 3. SSF = spatial scale filter; CR = complete response.

46 of the 50 non-CRs, providing an accuracy of 84.1% in identifying CR.

Two recent studies evaluated the role of texture analysis in assessing the response to chemoradiation in LARC and in predicting survival. Jalil et al[15] retrospectively assessed whether textural features extracted from MRI scans were able to predict survival. Fifty-six patients with LARC who underwent NCRT were included. They showed that of all textural features, mean of positive pixels (MPP) derived from pretreatment scans ($p = 0.008$) and skewness from the posttreatment scans ($p = 0.034$) were the only variables that could predict overall survival. Kurtosis of posttreatment scans ($p = 0.009$) and entropy of posttreatment scans ($p = 0.002$) were able to predict disease-free survival and relapse-free survival. In their study, they first did not correlate textural features with histological response, which would make more clinical sense. Their results also showed some of their textural features, such as MPP and entropy from posttreatment scans, were better predictors of overall survival than pathological complete response (pCR) and the presence of extramural venous invasion. Both parameters that were able to predict survival in their study, namely MPP and entropy from posttreatment scans, were also able to histologically identify patients with CR in our study.

Another study assessed the role of MRTA in assessing response to chemoradiation in LARC. De Cecco

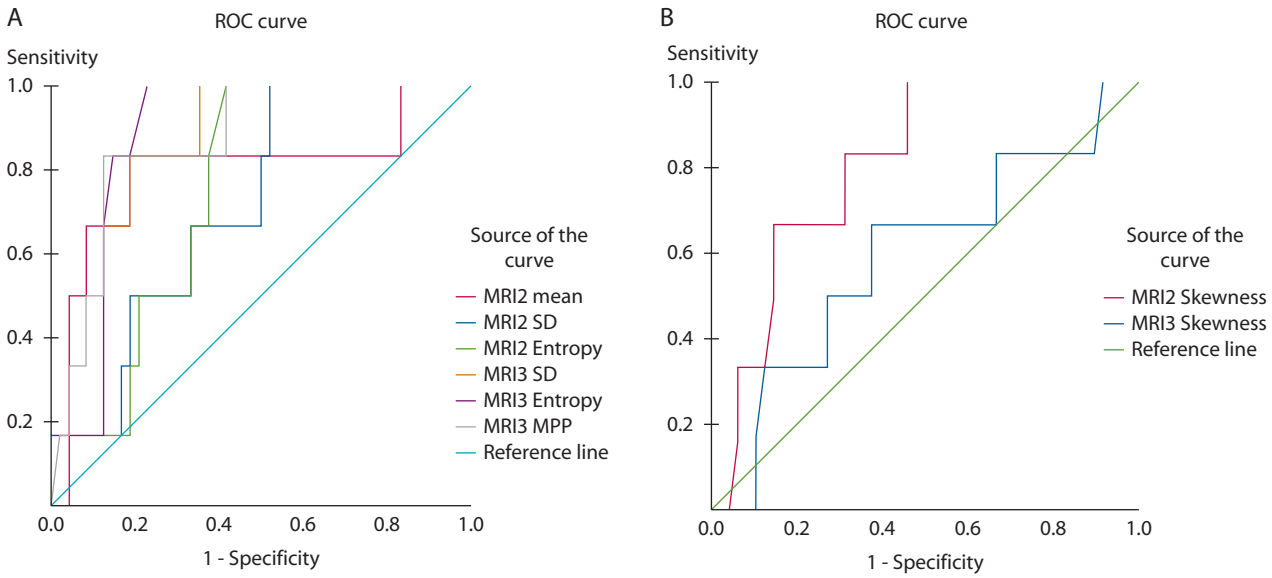

FIGURE 3. ROC curve of significant parameters from Mann-Whitney *U* test. A, Mean, SD, entropy, and mean of positive pixels. B, Skewness. MPP = mean of positive pixels; ROC = receiver operating characteristic.

et al[7] prospectively recruited 15 patients with LARC who underwent NCRT. They extracted textural features from pretreatment MRI and from midtreatment MRI, which was performed at day 21 of the 40-day NCRT. Six of those patients experienced pCR. They also assessed the relative change in textural features by measuring the absolute gradient between pre- and midtreatment parameters. They found that pretreatment kurtosis was significantly lower in those with pCR than in those with less than a complete response ($p = 0.01$), and that midtreatment kurtosis was significantly higher in pCR than in partial responders or nonresponders ($p = 0.045$). They also showed that change in kurtosis from pretreatment to midtreatment was also significantly higher in pCR than in non-pCR ($p = 0.038$). The AUC from ROC analysis was impressively 0.907 and, at the cutoff value of 0.19, resulted in sensitivity and specificity for CR prediction of 100% and 77.8%.

Texture parameters have therefore shown in multiple studies to carry important clinical significance in terms of assessing pathological outcomes and predicting survival. However, the procedure does come with limitations. The lack of concordance in the specific textural features that are able to identify CR among published studies is possibly due to the lack of a unified methodology in extracting those features in this relatively new modality.

Furthermore, selection of a single slice from the residual tumor might not be representative of the entirety of the cancer in terms of response to CRT. It can therefore be argued that this process is prone to sampling errors similar to sampling errors obtained from biopsies. However, the process used in our study has provided a high interrater reliability measure, which signifies that our process in choosing the MRI slice with the widest cross-sectional diameter through the midsection of the tumor and drawing the ROI by free hand is a reliable and reproducible method. Extracting textural features from a 3-dimensional lesion by expanding the ROI onto all the consecutive slices might diminish sampling errors. Furthermore, textural features were extracted from the midsection of the main body of the tumor, rather than specific areas in the scan that require further assessment. As a retrospective study, we were not able to separately extract textural features from, for example, medium-signal lymph nodes with a questionable cancer burden, outside the ROI. A prospective study would

TABLE 6. Optimal cutoff values of MRTA parameters in predicting CR after NCRT

MRTA parameters	*SSF*	*Area under curve*	*P value*	*Youden index*	*Optimal cutoff value*
MRI2					
Mean	0	0.795	0.019	0.645833	−165.625
Entropy	0	0.750	0.048	0.583333	5.84
Skewness	4	0.806	0.015	0.5416	0.26
MRI3					
SD	0	0.847	0.006	0.645833	103.845
Entropy	0	0.880	0.003	0.770833	5.745
MPP	0	0.866	0.004	0.708333	50.265

CR = complete response; MPP = mean of positive pixels; MRTA = MRI texture analysis; NCRT = neoadjuvant chemoradiotherapy; SSF = spatial scale filter.

further be able to specifically identify areas in a MRI scan that are being inspected, for example, a lymph node that gives an equivocal medium signal intensity, and therefore questionable cancer burden, and provide us with textural features and their pathological relations. Certainly, further prospective studies are required to understand the role and significance of texture analysis in assessing response to NCRT in LARC and in other cancers.

CONCLUSIONS

This study shows that MRTA, as an imaging biomarker, extracted from posttreatment MRI scans in patients with LARC, can in fact identify patients whose neoadjuvant treatment has resulted in CR. The accuracy of MRTA is at least comparable to both conventional MRI staging and to mrTRG in comparison with histological staging as the standard of reference. Those patients can then benefit from either a less invasive organ-sparing surgical approach or deferring from surgery altogether as a "watch and wait" approach.

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