Textural Differences in Apparent Diffusion Coefficient Between Low- and High-Stage Clear Cell Renal Cell Carcinoma

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OBJECTIVE. The purpose of this article is to evaluate differences in texture measures on apparent diffusion coefficient (ADC) maps between low- and high-stage clear cell renal cell carcinomas (RCCs).

MATERIALS AND METHODS. In this retrospective study, 61 patients with clear cell RCC at pathologic examination and who underwent preoperative MRI with diffusion-weighted imaging were included. Clear cell RCCs were clinically staged on review of preoperative MRI by a board-certified radiologist blinded to the pathologic findings. Whole lesions were segmented on ADC maps by two readers independently, from which first-order texture features (i.e., mean and skewness) and second-order texture features (i.e., cooccurrence matrix measures) were calculated. Texture metrics were compared between low- and high-stage clear cell RCC.

RESULTS. In 61 patients, there were 62 clear cell RCCs (33 low stage [stages I and II] and 29 high stage [stages III and IV]) at pathologic examination. Staging accuracy of qualitative interpretation was 100% for low-stage lesions and 37.9% (11/29) for high-stage lesions. There was no statistically significant difference in mean ADC between high- and low-stage clear cell RCCs (1.77 × 10−3 vs 1.80 × 10−3 mm2/s; p = 0.7). However, high-stage clear cell RCCs were larger (6.96 ± 2.93 vs 3.49 ± 1.57 cm; p < 0.0001) and had statistically significantly (p ≤ 0.0001) higher ADC skewness (0.02 ± 0.33 vs −0.52 ± 0.65) and cooccurrence matrix correlation (0.64 ± 0.11 vs 0.49 ± 0.13). Multivariate logistic regression identified size, skewness, and cooccurrence matrix correlation as significant independent predictors of high stage (AUC = 0.92). Interreader correlation in texture metrics ranged from 0.82 to 0.89.

CONCLUSION. First- and second-order ADC texture metrics differ between low- and high-stage clear cell RCCs. A model that includes size and ADC texture measures may help to stage clear cell RCCs noninvasively.

with the widespread availability of cross-sectional imaging, incidental renal neoplasms are being increasingly discovered [1, 2]. This leads to a management dilemma because renal tumors have variable prognoses [3–5]. Renal cell carcinoma (RCC) subtype plays an important role in determining aggressiveness. Clear cell RCC, the most common subtype, is more aggressive than other subtypes [6, 7]. Dynamic contrast-enhanced CT and contrast-enhanced MRI provide a relatively accurate method of differentiating clear cell from non–clear cell RCC subtypes [8–11].

The aggressiveness of clear cell RCCs and clinical outcome are also variable [12, 13]. Pathologic tumor grade and stage are independent factors that are useful in predicting the aggressiveness of clear cell RCC [14–16]. The TNM cancer classification system is used for clinicopathologic staging of clear cell RCCs. The TNM system is based on tumor size, tumor extension, lymph node involvement, and metastatic spread [16]. Stage I and II RCCs are defined as localized (confined within the kidneys) tumors without metastases (M0) or nodal involvement (N0). Stage I is defined as maximum linear extent of 7 cm or smaller; otherwise, the tumor is stage II. Localized or organ-confined stage I and II (low stage) clear cell RCCs have better prognosis and can mostly be treated with nephron-sparing surgery [17–21]. Less-invasive treatment options, such as ablation or even watchful waiting, are being investigated for low-stage tumors [22, 23]. Stage III and IV (high stage) clear cell RCCs, defined by extrarenal extension, have a worse prognosis [24]. Although these advanced stage RCCs are often treated with surgery, there
is a higher rate of recurrence [25]. Furthermore, there are ongoing clinical trials evaluating the role of neoadjuvant chemotherapy for stages III and IV clear cell RCC. Thus, the ability to accurately stage on imaging (before surgery) can provide prognostic information and can guide treatment.

CT and multiparametric MRI have been shown to have overall good accuracy for clinical staging of RCCs [14, 15], but it is challenging to discriminate stage III from stage I and II RCCs because of difficulties in identifying perirenal extension of the tumor as well as tumor involvement of the vasculature [26, 27]. It is commonly observed that high-stage clear cell RCCs show heterogeneity at both pathologic analysis and imaging, which may be related to cooccurrence of viable tumor, necrotic tissue, and hemorrhage.

Visual evaluation of image heterogeneity by a radiologist can be subjective. This can be resolved with the use of quantitative computer-aided analysis of texture features. First-order histogram distribution parameters, including kurtosis and skewness, reflect lesion heterogeneity. Second-order texture parameters, such as the cooccurrence matrix measures correlation, which represents a measure of the distribution of cooccurring gray-scale values at a given offset, describe more subtle aspects of lesion texture. These texture measures have recently been applied with some success in breast, brain, and abdominal imaging to distinguish benign from malignant lesions [28–31] and to assess tumor treatment response [32, 33].

Diffusion-weighted imaging (DWI) with quantitative apparent diffusion coefficient (ADC) measurement has shown promise in discriminating RCC subtypes and assessing clear cell RCC nuclear grade [34–36]. On the basis of these encouraging studies, the purpose of our investigation is to assess the utility of texture measures on ADC parametric maps in differentiating low-stage (I and II) from high-stage (III and IV) clear cell RCCs.

Materials and Methods

Patients

This study was HIPAA compliant and was approved by our institutional review board with a waiver of informed consent. A review of the pathology database was performed for patients who underwent surgery for renal neoplasm, either partial or total nephrectomy, at our institution from January 2008 to January 2011 with a diagnosis of clear cell RCC at pathologic evaluation. Patients who underwent preoperative MRI examination including DWI performed 180 days before surgery were included. A total of 288 patients underwent surgery and had a diagnosis of clear cell RCC. In 95 of these patients, MRI including DWI was performed before the surgery at our institution. This included 54 pathologically proven low-stage (I and II) lesions in 52 patients and 43 high-stage (III and IV) clear cell RCCs in 43 patients. MRI performed with different diffusion acquisition schemes (n = 8), severe artifacts on DWI precluding analysis (n = 3), renal mass protocols without IV gadolinium-based contrast material (n = 10), and renal lesion size less than 1 cm (n = 13) were excluded. The study cohort consisted of a total of 62 lesions in 61 patients (38 men [mean age, 64 years; age range, 41–76 years] and 23 women [mean age, 64 years; age range, 41–76 years]). In one patient with bilateral stage I clear cell RCCs, both lesions were included in the analysis.

MRI Technique

All patients underwent renal MRI on 1.5-T clinical systems (Avanto [n = 29], Symphony [n = 17], or Sonata [n = 15], all from Siemens Healthcare) using a torso phased-array coil. The MRI protocol included coronal and transverse plane HASTE, transverse in- and opposed-phase gradient-echo T1-weighted imaging, and dynamic 3D fat-suppressed gradient-echo T1-weighted imaging (volume interpolated breath-hold) performed before and after IV administration of gadolinium-chelate contrast material. All examinations included a fat-suppressed single-shot echo-planar DWI (performed before unenhanced and contrast-enhanced volume interpolated breath-hold sequences) in the transverse plane with tridirectional motion-probing gradients. Imaging was performed with b values of 0, 400, and 800 s/mm2. DWI was performed either with a navigator-triggered technique (n = 27) or as a breath-hold acquisition (n = 34). DWI sequence parameters are listed in Table 1. Acquisition time was under 20 seconds for breath-hold DWI and varied according to the patient’s respiratory cycle for respiratory-triggered DWI (mean acquisition time, 2 minutes 20 seconds). ADC maps were constructed on

### Table 1: Parameters of Diffusion-Weighted Imaging Sequence

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Breath-Hold</th>
<th>Navigator-Triggered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging plane</td>
<td>Transverse</td>
<td>Transverse</td>
</tr>
<tr>
<td>TR/TE</td>
<td>1500–2000/65–85</td>
<td>One respiratory cycle/65–85</td>
</tr>
<tr>
<td>Matrix</td>
<td>144–192 × 192</td>
<td>144–192 × 192</td>
</tr>
<tr>
<td>Section thickness (mm)</td>
<td>6–8</td>
<td>6–8</td>
</tr>
<tr>
<td>Receiver bandwidth (Hz/voxel)</td>
<td>1300–1630</td>
<td>1300–1630</td>
</tr>
<tr>
<td>Parallel imaging factor</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>b values (s/mm²)</td>
<td>0, 400, 800</td>
<td>0, 400, 800</td>
</tr>
</tbody>
</table>

### Table 2: Cooccurrence Matrix Features Compared Between Low- and High-Grade Renal Cell Carcinoma

<table>
<thead>
<tr>
<th>Cooccurrence Matrix Features</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast</td>
<td>Measure of gray-level pixel differences</td>
</tr>
<tr>
<td>Correlation</td>
<td>Measurement of gray-level linear dependencies</td>
</tr>
<tr>
<td>Angular second moment</td>
<td>Measure of order (gray-level homogeneity)</td>
</tr>
<tr>
<td>Inverse difference moment</td>
<td>Measure of the dominance of low-intensity pixel pairs</td>
</tr>
<tr>
<td>Sum average</td>
<td>Sum of mean of gray-level pixel values</td>
</tr>
<tr>
<td>Sum of squares</td>
<td>Sum of squared differences in gray-level pixel values from the overall mean</td>
</tr>
<tr>
<td>Difference variance and sum variance</td>
<td>Measures of dispersion of gray-level pixel values around the mean</td>
</tr>
<tr>
<td>Sum entropy, entropy, and difference entropy</td>
<td>Measures of disorder (gray-level heterogeneity)</td>
</tr>
</tbody>
</table>
Differences in ADC Texture Between Low- and High-Stage Clear Cell RCC

**TABLE 3: Qualitative MRI Features of Low- and High-Stage Clear Cell Renal Cell Carcinomas (RCCs)**

<table>
<thead>
<tr>
<th>MRI Features</th>
<th>Low-Stage RCCs (n = 33)</th>
<th>High-Stage RCCs (n = 29)</th>
<th>Understaged RCCs(^a) (n = 18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (cm), mean ± SD</td>
<td>3.49 ± 1.57</td>
<td>6.96 ± 2.93</td>
<td>7.35 ± 3.26</td>
</tr>
<tr>
<td>T1 signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isointense</td>
<td>8 (24)</td>
<td>10 (34)</td>
<td>7 (39)</td>
</tr>
<tr>
<td>Hypointense</td>
<td>22 (67)</td>
<td>16 (53)</td>
<td>11 (61)</td>
</tr>
<tr>
<td>Hyperintense</td>
<td>2 (6)</td>
<td>3 (10)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>T2 signal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isointense</td>
<td>4 (12)</td>
<td>10 (35)</td>
<td>5 (28)</td>
</tr>
<tr>
<td>Hypointense</td>
<td>3 (9)</td>
<td>2 (7)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Hyperintense</td>
<td>26 (79)</td>
<td>17 (59)</td>
<td>13 (72)</td>
</tr>
</tbody>
</table>

Note—Except where noted otherwise, data are number (%) of RCCs.

\(^a\)Subgroup of stage III lesions that were inappropriately classified as low stage on conventional MRI.

**Results**

**Lesions**

At clinicopathologic staging, there were 33 low-stage (29 stage I and four stage II) and 29 high-stage (25 stage III and four stage IV) clear cell RCCs. The mean time interval between MRI and surgery was 21 days (range, 1–119 days).

**Qualitative Assessment**

There was no statistically significant difference in T1- and T2-weighted signal between low- and high-stage lesions (Table 3). Overall staging accuracy on qualitative evaluation was 71% (44/62). When stratified by stage, accuracy was 100% (33/33) for low-stage and 37.9% (11/29) for high-stage lesions. Twenty-nine stage I, four stage II, and four stage IV lesions were accurately staged. Only 28% (7/25) of stage III lesions were staged accurately on conventional anatomic imaging. These lesions were understaged as either stage I (n = 9) or stage II (n = 9). This understaged subgroup (n = 18) was also analyzed separately.

**Size**

High-stage lesions were statistically significantly larger than low-stage clear cell RCCs (6.96 ± 2.93 vs 3.49 ± 1.57 cm; p < 0.0001). Understaged subgroup lesions were also statistically significantly larger than low-stage lesions (7.35 ± 3.26 vs 3.49 ± 1.57 cm; p < 0.0001) (Table 3).

**Quantitative Assessment**

There was no statistically significant difference in mean ADC between high- and low-stage clear cell RCCs (1.77 × 10\(^{-3}\) ± 0.29 × 10\(^{-3}\) vs 1.80 × 10\(^{-3}\) ± 0.34 × 10\(^{-3}\) mm\(^2\)/s; p = 0.7). The mean ADC in the understaged subgroup was also not statistically significantly different from that in low-stage clear cell RCC (1.79 × 10\(^{-3}\) ± 0.24 × 10\(^{-3}\) vs 1.80 × 10\(^{-3}\) ± 0.34 × 10\(^{-3}\) mm\(^2\)/s; p = 0.94).

Table 4 summarizes the quantitative first- and second-order texture features evaluated within the study cohort. Skewness was statistically significantly higher in high-stage than in low-stage clear cell RCCs (0.02 ± 0.33 vs −0.52 ± 0.65; p = 0.0001), with negative skew in low-stage clear cell RCC. There was a trend for kurtosis to be lower in high-stage than in low-stage clear cell RCCs (0.51 ± 0.73 vs 1.50 ± 2.00), but this difference did not reach a pixel-wise basis for each case on a commercial workstation (Leonardo, Siemens Healthcare) using the b values of 0, 400, and 800 s/mm\(^2\) and a monoexponential fit.

**Image Texture Analysis**

Two independent readers, who were blinded to the histologic staging, used in-house developed software [37] as well as MaZda software (The Technical University of Lodz, Institute of Electronics, Poland) [38, 39] to perform quantitative analysis of ADC maps. Both of these programs allowed placement of 3D volumes of interest (VOIs) encompassing multiple slices. For each lesion, an ROI was drawn on every slice that included the mass on the ADC map, just inside the outer margin of the lesion to minimize partial volume error, to generate a VOI of the mass. The superior and inferior most slices were excluded to avoid volume averaging. Within each lesion VOI, the in-house developed software was used to perform mean ADC measurements. The MaZda software was used to obtain histogram and texture metrics, including variance, skewness, and kurtosis, according to histogram bin width (× 10\(^{-5}\) mm\(^2\)/s) [33, 38], as well as 11 cooccurrence matrix measurements for each lesion VOI (Table 2). Cooccurrence matrix parameters represent the probability of occurrence of a pixel pair with a given gray-tone difference, separated by a predefined distance taken in a predefined orientation [38, 39]. Cooccurrence matrix parameters were computed for a distance of one voxel and in directions of 0°, 45°, 90°, and 135° [38–40]. Parameters were then averaged over the four directions, because no directional variations in texture were expected [28]. The lesion VOI placement and measurement of texture parameters using MaZda software were performed in approximately 5–7 minutes per lesion.

**Lesion Size, Stage, and Qualitative Evaluation**

A board-certified radiologist, who was unaware of histologic findings, recorded the largest diameter of the mass. The same reader performed staging on MRI using the 2009 TNM classification [41]. In addition, each renal lesion was characterized as hypo-, hyper-, or isointense, with respect to renal cortex, on T1- and T2-weighted images. In heterogeneous lesions, the solid nonnecrotic component was used to determine the intensity relative to the renal cortex on T1- and T2-weighted images.

**Statistical Analysis**

Qualitative binary imaging features were assessed for statistically significant differences between low- and high-stage clear cell RCCs using the Fischer exact test. Each quantitative measure (tumor size, mean ADC, first-order histogram parameters [variance, kurtosis, and skewness], and second-order texture parameters [cooccurrence matrix correlation]) were represented for each subject as an average over readers. Low- and high-stage tumors were compared in terms of averages using unequal-variance Student t tests for all quantitative features. It is noted that the sample sizes were considered adequate for an asymptotic justification of the underlying normality assumption. Stepwise variable selection in the context of binary logistic regression was used to identify sets of measures constituting significant independent predictors of high-grade tumor. An ROC analysis was used to assess the diagnostic utility of selected logistic models for the detection of high-stage tumors. Interreader agreement was characterized using the intraclass correlation coefficient. All statistical tests were conducted at the two-sided Bonferroni-corrected significance level of α = 0.0025 (i.e., α = 0.05/20, where 20 is the number of measures compared) using SAS software (version 9.3, SAS Institute).
statistical significance when correcting for multiple comparisons ($p = 0.011$).

Cooccurrence matrix correlation was statistically significantly higher in high-stage compared with low stage clear cell RCC ($0.64 \pm 0.11$ vs $0.49 \pm 0.13; p < 0.0001$). Two other cooccurrence matrix features (sum of variance and sum of squares) were higher in high-stage clear cell RCC but this difference did not reach statistical significance after correcting for multiple comparisons ($p > 0.0025$) (Table 4).

The understaged subgroup showed significantly higher skewness ($-0.10 \pm 0.21$ vs $-0.52 \pm 0.65; p = 0.002$) and higher cooccurrence matrix feature correlation ($0.62 \pm 0.12$ vs $0.49 \pm 0.13; p < 0.001$) compared with low-stage clear cell RCC. Figures 1–3 illustrate examples of low-stage, understaged, and high-stage clear cell RCCs with accompanying texture feature measures for each lesion.

There was good-to-excellent interreader correlation in histogram and texture metrics, with intra- and interclass correlation coefficients ranging from 0.82 to 0.89. Furthermore, there was no statistically significant difference in the texture parameters kurtosis, skewness, and cooccurrence matrix correlation between the breath-hold and navigator triggered acquisition when clear cell RCCs were stratified by stage (Table 5).

Multivariate logistic regression identified size ($p = 0.013$), skewness ($p = 0.012$), and cooccurrence matrix correlation ($p = 0.030$) as significant independent predictors of high-stage tumor. The logistic model defined by these three parameters achieved an AUC of 0.92, with sensitivity of 86% and fixed specificity of 80% (95% CI, 65.5–93.1%).

**Discussion**

We used whole-lesion texture analysis to evaluate low- and high-stage clear cell RCCs. High-stage clear cell RCCs were statistically significantly larger with lower kurtosis and higher skewness. Skewness was statistically significantly different, whereas kurtosis did not reach statistical significance after correcting for multiple comparisons. The cooccurrence matrix correlation was also statistically significantly different between the two groups after correcting for multiple comparisons. Importantly, texture features were useful in accurate classification of lesions that were understaged with conventional anatomic imaging.

The assessment of tumor heterogeneity is emerging as a practical clinical tool [40]. Several studies of extrarenal lesions have suggested that increasing heterogeneity on CT and MRI is associated with malignancy [38–40]. The first-order histogram features kurtosis and skewness reflect tumor heterogeneity and have been shown to be useful in assessing treatment response in tumors involving the head and neck [42], brain [33], breast [43], and cervix [31]. Furthermore, these parameters have been used to differentiate clear cell from papillary RCCs [44]. However, to our knowledge, there has been no attempt to use kurtosis and skewness to assess RCC stage.

Our key observation is the presence of lower negative ADC skewness for the low-stage clear cell RCCs, versus approximately zero skewness for high-stage RCCs. A negative skew indicates an asymmetry, with the left tail of the histogram being longer than the right side. Zero skewness indicates that the values are relatively evenly distributed on both sides of the mean, typically implying a symmetric distribution. Kurtosis represents the degree of peakedness of a histogram, with an acute peak (as compared with a bell-shaped gaussian distribution) reflecting high kurtosis and a broad curve representing low values. Our finding of lower ADC kurtosis in stage III and IV lesions likely reflects increased lesion heterogeneity secondary to increased cellularity, necrosis, and hemorrhage seen in these more aggressive lesions.

The intravoxel incoherent motion model of diffusion suggests that blood flow in microvasculature contributes to the diffusion signal and ADC measurement [45, 46]. Previous studies of intravoxel incoherent motion in renal tumors have shown increased perfusion fraction in enhancing RCCs, compared with benign renal masses, and higher perfusion fraction in clear cell when compared with papillary RCCs [47, 48]. Heterogeneity both in vascular and tissue diffusion component may contribute to the ADC heterogeneity as seen in high-stage clear cell RCC. Thus, skewness and kurtosis of ADC histograms may capture differences in tumor microenvironments that may be masked by mean ADC analysis.
Second-order texture parameters use spatial gray-level dependence based on subtle interactions of neighboring voxels [40]. Using contrast-enhanced MRI, cooccurrence matrix measures have been used to differentiate benign from malignant breast lesions [28, 49], assess the stage of liver fibrosis [50], and assess neurodegeneration in Alzheimer disease [51]. To our knowledge, there have been no prior examinations of second-order texture measures in the evaluation of RCC. The cooccurrence matrix reflects the frequency with which pairs of voxels with a given signal intensity contrast find themselves within a certain spatial relationship [40]. We found three of 

Fig. 1—56-year-old man with stage I clear cell renal cell carcinoma (RCC) at pathologic evaluation. 
A. On contrast-enhanced corticomedullary phase image, there is avid and mildly heterogeneous enhancement. 
B. On apparent diffusion coefficient (ADC) map, lesion has low ADC value and homogeneous appearance. 
C. Whole-lesion ADC histogram revealed high kurtosis value of 2.01, negative skewness of −1.31, and lower cooccurrence matrix correlation value of 0.35, compatible with low-stage lesion.

Fig. 2—66-year-old man with stage III clear cell renal cell carcinoma (RCC) at pathologic evaluation. Lesion was understaged (as stage I) on qualitative visual evaluation. 
A. On contrast-enhanced corticomedullary phase image, there is hypervascularity and heterogeneous enhancement. 
B. On apparent diffusion coefficient (ADC) map, lesion shows heterogeneity with intermingled areas of low and high ADC value. 
C. Whole-lesion ADC histogram revealed low kurtosis value of 0.29, positive skewness of 0.20, and high cooccurrence matrix correlation value of 0.82, compatible with high-stage clear cell RCC.
Despite the observed usefulness of cooccurrence matrix measures in differentiating low- from high-stage clear cell RCC, the importance of lesion size cannot be understated. An association between patient survival and RCC tumor size, irrespective of TNM stage, has been previously reported [55]. Furthermore, it has been shown that each 1 cm increase in RCC tumor size is associated with a 35% increase in renal capsule involvement and 66% renal vascular invasion [56]. We found stage III and IV clear cell RCCs to be statistically significantly larger than stage I and II RCCs, measuring 6.96 and 3.49 cm, respectively. Prior studies using Robson staging criteria have similarly shown larger tumors to be associated with higher stage [57]. An investigation using the 1997 TNM staging system found mean RCC sizes on MRI of 3.2 cm for T1, 14.2 cm for T2, and 9.2 cm for T3 [14]. The smaller relative RCC sizes in our patient cohort compared with those in the previous study may represent the current increased detection of incidental RCCs, which are often imaged at a smaller size than in the past.

The qualitative staging accuracy in our study cohort was 71%, with all inaccuracies attributed to understaging of T3 lesions, secondary to the inability to identify perinephric fat invasion. Prior studies reported accuracies for staging RCC using CT and MRI that are similar to or slightly higher than those in our study, in the range of 74–86% and 67–90%, respectively [14, 58–60]. The most recent study using MRI to predict preoperative RCC stage using the 1997 TNM guidelines had a staging accuracy of 81–86%, with most staging errors resulting from overstaging of T2 tumors as T3 [14]. When stratified by stage, accuracy was 100% for T1, 50% for T2, and 75% for T3 [14]. Thus, discriminating low stage (T2) from high stage (T3) is problematic on conventional imaging, and additional methods such as texture analysis may improve staging accuracy.

The retrospective nature of our study was a limitation. However, the goal of this study was to identify texture parameters in ADC maps that may help discriminate low- and high-stage clear cell RCC with histopathology as a reference. Furthermore, the same dataset was used to create a model and to test its accuracy. To guard against overfitting the data (i.e., building a model that is overly complex and not generalizable), we have used a limited number of key texture measures by ignoring directional textures. Future studies would be helpful to validate our preliminary observations and to test this in an independent cohort. We evaluated only the most
common and most aggressive subtype of RCC, not the other less aggressive subtypes, which have a lower incidence of occurrence. Our texture analysis was performed on ADC images from three different 1.5-T MRI scanners. However, a previous investigation involving brain MRI texture of intracranial tumors reported highly reproducible results of second-order features acquired with multiple MRI scanners [61]. There was no statistically significant difference in texture parameters between the breath-hold and navigator acquisition schemes when stratified by stage, likely because of sufficient signal-to-noise ratio with both acquisition schemes.

In conclusion, our study shows that, in spite of a lack of statistically significant differences in mean ADC between low- and high-stage clear cell RCCs, texture metrics are statistically significantly different between these groups. These differences persisted in a subgroup of high-stage clear cell RCCs that were inaccurately staged as lower stage clear cell RCCs on qualitative interpretation of conventional MRI. Thus, ADC textural analysis of clear cell RCCs can provide a noninvasive means of accurately identifying high-stage tumors on preoperative imaging and help guide management.

Acknowledgment

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