Combined Late Gadolinium-Enhanced and Double-Echo Chemical-Shift MRI Help to Differentiate Renal Oncocytomas With High Central T2 Signal Intensity From Renal Cell Carcinomas

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**OBJECTIVE.** The purpose of our study was to evaluate the combination of dynamic contrast-enhanced T1-weighted and double-echo gradient-echo MRI using nephron-sparing surgery [2, 4] when technically feasible. The importance of preoperative diagnosis is thus crucial, and, although some renal tumors [12, 13] as a tumor segment with a lower density at the arterial phase and a higher density at the early excretory phase. This last feature was observed in indeterminate small renal masses without a scar and is associated, according to Kim et al. [12], with differences in hypocellular hyalinized stroma content within the tumor parenchyma. However, these results have not been confirmed by others [10, 13]. Using MRI, Rosenkrantz et al. [14] observed a comparable contrast inversion in 28.6% of oncocytomas and 13.3% of renal cell carcinomas (RCCs) but without differentiating inversions within the tumor parenchyma or with contrast enhancement within the central scar itself.

**RESULTS.** There were 19 oncocytomas (16 patients), 43 RCCs (42 patients), and one leiomyoma. Complete late enhancement of the central area was observed in 14 oncocytomas (74%) and in five RCCs (12%) (p = 0.05). The combination of complete enhancement and SI index lower than 2% (p = 0.02) or tumor-to-spleen ratio higher than −6% (p = 0.001) provided sensitivity of 36% and 55%, specificity of 95% and 97%, positive predictive value of 67% and 86%, and negative predictive value of 84% and 88%, respectively, for diagnosis of oncocytomas.

**CONCLUSION.** Absence of central area SI inversion or presence of a signal drop on chemical-shift imaging may rule out the diagnosis of oncocytoma.

Renal oncocytoma is considered a benign tumor, representing 3–7% of all renal tumors [1]. Apart from exceptional cases of renal carcinomas coexisting as hybrids or separate tumors, the prognosis is considered excellent [1–3]. On the basis of these considerations, conservative treatment can be recommended using nephron-sparing surgery [2, 4], when technically feasible. The importance of preoperative diagnosis is thus crucial, and, although the literature on characteristic features of renal oncocytomas abounds, until now, no imaging techniques have been identified that can accurately separate oncocytomas from malignant lesions [3, 5, 6]. Thus, diagnosis of oncocytoma remains based on histopathologic examination of surgical or biopsy specimens [7, 8] showing large eosinophilic cells with small round nuclei with large nucleoli, apical Hale coloration, and no expression of cytokeratin 7 and vimentin [9].

Recent studies have attempted to identify these benign tumors with contrast-enhanced CT according to an evaluation of the gradual enhancement after contrast injection [10] and the wash-in and washout of the contrast agent [11], which offer only low sensitivity and specificity. More recently, a segmental enhancement inversion was described within some renal tumors [12, 13] as a tumor segment with a lower density at the arterial phase and a higher density at the early excretory phase. This last feature was observed in indeterminate small renal masses without a scar and is associated, according to Kim et al. [12], with differences in hypocellular hyalinized stroma content within the tumor parenchyma. However, these results have not been confirmed by others [10, 13]. Using MRI, Rosenkrantz et al. [14] observed a comparable contrast inversion in 28.6% of oncocytomas and 13.3% of renal cell carcinomas (RCCs) but without differentiating inversions within the tumor parenchyma or with contrast enhancement within the central scar itself.

Morphologically, a central scar is found in 54% [5] to 80% [2] of renal oncocytomas. It

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was classically considered as evocative of this tumor type [15], but it is also observed in 30–40% of chromophobe carcinomas [14]. However, when a central area with high signal intensity (SI) on T2-weighted images is present within a tumor, the question of central necrosis within classic renal cell carcinoma still arises [16]. Whereas fibrous scars of hepatic focal nodular hyperplasia show delayed enhancement on gadolinium-enhanced T1-weighted sequences [17], such patterns in renal oncocytomas have received only little attention.

Because of signal loss on opposed-phase images, double-echo chemical-shift MRI sequences can detect small amounts of fat in atypical angiomylipomas or intracellular lipids in clear cell and papillary carcinomas [18]. According to Rosenkrantz et al. [14], no change of signal intensity occurred in oncocytomas and chromophobe carcinomas.

The objective of this study was to evaluate the combination of dynamic contrast-enhanced T1-weighted and double-echo gradient-echo MRI in tumors presenting with a central area compatible with central scar or central necrosis to distinguish renal oncocytoma with high T2 SI centrally from RCC.

Materials and Methods

Patient Selection

Institutional review board approval was obtained for this retrospective study; informed patient consent was not required according to local laws. All patients examined with MRI for renal lesions in our institution between January 2006 and August 2011 were retrospectively selected from our prospectively maintained institutional database (Fig. 1). All cases identified were reviewed by two genitourinary radiologists with 5 and 1 years of experience blinded to the pathology review. Final results reviewed the MR images in consensus on a PACS workstation. Enhancement within the central area of these tumors was assessed visually. An SI inversion was considered to be present when, on late images, the central area presented an SI greater than the SI on peripheral tumoral tissues. This SI inversion was qualified as complete when including the entire central area and partial when only one part of this area showed enhancement.

The quantitative measurement of intratumoral lipid content was performed after drawing a region of interest (ROI) including the whole tumor and the central area, matched on in phase and opposed phase images. The change of SI was quantified using the SI index and the tumor-to-spleen ratio as previously proposed [19].

\[
SI\text{ index } = \frac{[TuSI_{in} - TuSI_{opp}]}{TuSI_{in}} \times 100,
\]

where TuSI_{in} and TuSI_{opp} are tumor SI on in phase and opposed phase images; tumor-to-spleen ratio = \[
\frac{[SpSI_{in} - SpSI_{opp}]}{SpSI_{in}} - 1 \times 100,
\]

where SpSI_{in} and SpSI_{opp} are spleen SI on in phase and opposed phase images.

Image Analysis

Two genitourinary radiologists with 5 and 20 years of experience blinded to the pathology results reviewed the MR images in consensus on a PACS workstation. Enhancement within the central area of these tumors was assessed visually. An SI inversion was considered to be present when, on late images, the central area presented an SI greater than the SI on peripheral tumoral tissues. This SI inversion was qualified as complete when including the entire central area and partial when only one part of this area showed enhancement.

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\frac{[SpSI_{in} - SpSI_{opp}]}{SpSI_{in}} - 1 \times 100,
\]

where SpSI_{in} and SpSI_{opp} are spleen SI on in phase and opposed phase images.

Histopathology Analysis

Histopathologic diagnosis was available for all tumors after a percutaneous biopsy using an 18-gauge automated side-cutting needle (Monopuncture Disposable Core Biopsy Instrument, Bard) or surgical excision, which was reviewed retrospectively by a uropathologist with more than 30 years of experience. Tumors removed surgically were reanalyzed to determine the exact composition of the central areas. All tumors were fixed in acetonic-formaldehyde, and cut tumor fragments were embedded in paraffin after dehydration. H and E was used to stain 3- or 4-µm sections, followed by immunostaining using vimentin, cytokeratin 7, CD10, CD117, and Hale colloidal iron.

Statistical Analysis

All patient data were acquired by one of the authors through review of medical records and imaging and pathology reports. Statistical significance to compare SI inversion in renal oncocytomas and RCCs was calculated using the Fisher exact test (Excel, Microsoft) and p values less than 0.05 were considered significant. SI index and tumor-to-spleen ratio were compared between oncocytomas and RCCs using the Student t test. To assess the diagnostic performance of SI inversion for differentiation of oncocytomas from RCCs, we calculated sensitivity,

![Fig. 1—Flowchart shows study profile on basis of recommended standards for reporting diagnostic accuracy.](image-url)
TABLE 1: MRI Protocol

<table>
<thead>
<tr>
<th>MRI Protocol</th>
<th>MRI Sequence</th>
<th>Late T1-Weighted Water-Select Gradient-Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1-Weighted Gradient-Echo</td>
<td>T2-Weighted Fast Spin-Echo</td>
</tr>
<tr>
<td>Plane</td>
<td>Axial</td>
<td>Axial</td>
</tr>
<tr>
<td>Fat saturation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>TR (ms)</td>
<td>182</td>
<td>2112</td>
</tr>
<tr>
<td>TE (ms)</td>
<td>4.6–2.3</td>
<td>100</td>
</tr>
<tr>
<td>Angulation (°)</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>FOV (mm)</td>
<td>375</td>
<td>325</td>
</tr>
<tr>
<td>Matrix (mm × mm)</td>
<td>220 × 284</td>
<td>268 × 344</td>
</tr>
<tr>
<td>Scanning time (s)</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>Delay (s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2—39-year-old woman with renal tumor.

A, Axial T2-weighted image (TR/TE, 2112/100; flip angle, 90°) shows left renal tumor isointense to renal cortex with central area of high signal intensity (arrow).

B and C, Axial in phase (B) and opposed phase (C) T1-weighted gradient-echo images (TR/TE range, 182/4.6–2.3; flip angle, 70°) show no variation of signal intensity.

D, Dynamic axial T1-weighted images (TR/TE, 3.9/1.8; flip angle, 10°) without fat suppression obtained 40 seconds (upper left), 2 minutes (upper right), 2.5 minutes (lower left), and 4.1 minutes (lower right) after gadolinium injection. Peripheral tumor component shows fast enhancement, whereas central area shows no enhancement.

E, Delayed (10 minutes) water-select image (TR/TE, 235/5; flip angle, 80°) shows no central enhancement.

F, Macroscopic photograph shows brown tumor with whitish stellate central scar (arrow). Microscopic examination (not shown) showed scar is fibrous with edematous rearrangements in which there were few capillaries without tumor cells, corresponding to leiomyoma.
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**Results**

**Patients**

A total of 59 patients (35 men and 24 women; mean age, 63 years; range, 25–83 years) with 63 tumors were selected for the study from the institutional radiologic database. No further patients were identified in the pathology database. Histopathologic diagnosis was obtained after surgical excision of the tumors in 50 patients and exclusive percutaneous biopsy in nine. Overall, 26 tumors were percutaneously biopsied before any therapeutic decision. No change in the initial pathologic diagnosis in those patients who first underwent biopsy and then had surgical removal was reported.

**Lesions**

The mean size ± SD (range) of tumors was 39.9 ± 21.8 mm (18–103 mm) for oncocytomas, 51.4 ± 23 mm (17–101 mm) for RCC, and 96 mm for the leiomyoma. Overall, 19 tumors were oncocytomas in 16 patients (one patient had an oncocytomatosis with six tumors but only four had a central scar on T2-weighted images), 43 were RCCs (42 patients), and one was a leiomyoma (Fig. 2). Among the RCCs, 32 were clear cell carcinomas, seven were papillary carcinomas, and four were chromophobe carcinomas.

**Enhancement Analysis**

The SI inversion analysis observed on late contrast-enhanced T1-weighted images is reported in Tables 2 and 3. A complete SI inversion was observed in 19 cases overall and, in all cases but one, only on late contrast-enhanced images (> 6 minutes after injection). Except in the case of oncocytomas (Fig. 3), the tumor type in this situation was a clear cell carcinoma in four cases (Fig. 4) and a chromophobe in one. When SI inversion was partial (n = 38), it always appeared at the periphery of the central area as a thin rim along the junction with the tumor component (Fig. 5).

**Chemical-Shift Imaging Analysis Between Oncocytomas and Renal Cell Carcinoma Groups**

Results of the chemical-shift imaging analysis between oncocytomas and RCC groups are summarized in Tables 3 and 4 and Figure 6. Optimal cutoff values of SI index of 2% and for tumor-to-spleen ratio of −6% were extracted from the ROC curve analysis (Fig. 7) for differentiation of the two groups. This means that a tumor with an SI index lower than 2% or a tumor with a tumor-to-spleen ratio greater than −6% was considered an oncocytoma.

**Combination of Enhancement Analysis and Chemical-Shift Imaging for the Differentiation of Oncocytomas From Renal Cell Carcinomas**

For the differentiation of oncocytomas from RCCs, the combination of a complete central SI inversion on gadolinium-enhanced images and a low SI index (cutoff value of 2%) provided sensitivity of 36%, specificity of 95%, PPV of 67%, and NPV of 84%. The combination of a complete central SI inversion on gadolinium-enhanced images and a smaller tumor-to-spleen ratio (cutoff value of −6%) gave sensitivity of 55%, specificity of 97%, PPV of 86%, and NPV of 88% (Table 3).

**Pathology**

Among the 19 oncocytomas, 13 were managed nonoperatively after percutaneous biopsy with basic imaging follow-up for 11 cases and percutaneous radiofrequency ablation for two. For these cases, no histopathologic information was available about central scarring. Gross pathology was available in the six operated oncocytomas. Only five presented with a complete central SI inversion: the scar always appeared macroscopically as a whitish area (Fig. 3F), corresponding microscopically to an edematous and fibrohyaline tissue containing myofibroblasts, capillaries, and thin collagen fibers and persistent oncocyti cells (Fig. 3G). In the resected lesion with an incomplete inversion, pathologic analysis

### Table 2: Late Contrast-Enhanced MRI Analysis

<table>
<thead>
<tr>
<th>Enhancement of Central Area (Signal Inversion)</th>
<th>Oncocytoma (n = 19)</th>
<th>Renal Cell Carcinoma (n = 43)</th>
<th>Leiomyoma (n = 1)</th>
<th>p by Fisher Exact Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>5 (12)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Incomplete</td>
<td>5 (26)</td>
<td>33 (77)</td>
<td>0</td>
<td>0.57</td>
</tr>
<tr>
<td>Complete</td>
<td>14 (74)</td>
<td>5 (12)</td>
<td>0</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Note—Data in parentheses are range.

### Table 3: Accuracy for Differentiation of Oncocytomas From Renal Cell Carcinomas for All Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Differentiation</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal intensity inversion analysis</td>
<td>Incomplete</td>
<td>26</td>
<td>23</td>
<td>13</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Complete</td>
<td>74</td>
<td>88</td>
<td>74</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Incomplete or complete</td>
<td>100</td>
<td>9</td>
<td>33</td>
<td>100</td>
</tr>
<tr>
<td>Chemical shift imaging analysis</td>
<td>Signal intensity index &lt; 2%</td>
<td>50</td>
<td>50</td>
<td>79</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Tumor-to-spleen ratio &gt; −6%</td>
<td>70</td>
<td>73</td>
<td>41</td>
<td>90</td>
</tr>
<tr>
<td>Combination of both criteria</td>
<td>Complete signal intensity inversion and signal intensity index &lt; 2%</td>
<td>36</td>
<td>95</td>
<td>67</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Complete signal intensity inversion and tumor-to-spleen ratio &gt; −6%</td>
<td>55</td>
<td>97</td>
<td>86</td>
<td>88</td>
</tr>
</tbody>
</table>
showed macroscopically a more yellowish appearance, corresponding with hyaline tissue with lower cellularity (less fibroblast, less collagen, and no oncocytic cells).

Gross pathology was available after surgical resection for the leiomyoma and for all RCCs. For the central area of the leiomyoma, gross pathology showed a fibrous scar with edematous rearrangements in which there were few capillaries without tumor cells.

The five carcinomas with complete SI inversion of the central area were all resected: four clear cell carcinomas and one chromophobe carcinoma. Pathologic analysis showed that the central area corresponded with a fibrotic component with a low level of necrosis and a few capillaries without persistent tumor cells (Figs. 4E and 4F). In the 32 cancer lesions without complete SI inversion, only necrosis was present centrally.

**Discussion**

Characterizing tumors before deciding on the most appropriate treatment is a general rule in oncology. However, pretherapeutic characterization of renal tumors is still problematic in clinical practice. The high prevalence of RCC and the lack of reliable imaging criteria for recognition of benign tumors other than typical angiomylipoma justify the growing role of pretherapeutic imaging-guided biopsy. Diagnosis of oncocytoma and low-fat-content angiomylipoma remains a challenge [7, 8]. Validation of new imaging criteria would be useful before deciding on any therapeutic option and to avoid total nephrectomy when possible.

In this retrospective series of renal masses on MRI, the high prevalence of oncocytomas (16/63, 25.4%) has three main causes. The first is that, in our clinical practice, MRI was often indicated when this tumor type was suspected on CT, as proposed by Kim et al. [12], and to look for microscopic fat content enabling us to rule out the hypothesis of oncocytoma where applicable [14, 18]. The second is that if a renal tumor presented a central area and any typical malignant patterns on CT, as described previously in some cases of RCC [12, 14], this mass was usually not imaged with MRI and, in consequence, the rate of benign tumors increased. Finally, our study only evaluated tumors with high central T2 signal intensity, which probably increased the rate of oncocytomas relative to their actual prevalence.
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RCCs by excluding all cancers that did not have central necrosis or fibrosis.

Our study provides some important results. First, all oncocytomas with central areas presented late central SI inversions within the central scar, responsible for a contrast inversion that was either complete or incomplete. Second, examples of all subtypes of RCC, not only chromophobes, showed complete or partial central SI inversions. Third, a signal loss on opposed phase images, especially after the calculation of SI index and tumor-to-spleen ratio, was significantly more frequently observed in all subtypes of RCC than oncocytoma. In other words, absence of central area SI inversion or presence of a signal drop on chemical-shift imaging can be used to rule out the diagnosis of oncocytoma.

We decided to retrospectively focus on the late gadolinium enhancement of central areas of renal tumors on the basis of experience with focal nodular hyperplasia, which shows central fibrous tissue with delayed enhancement [17]. Our study showed that most central fibrous scars enhance slowly after injection of gadolinium, justifying performing late T1-weighted sequences after injection, later than 5 minutes, when an oncocytoma was suspected on T2-weighted imaging or CT.

This late SI inversion explains why it has never been described with CT, the late excretory phase usually being performed only 3 minutes after injection. The segmental SI inversion between the corticomedullary phase and the early excretory phase recently described by Kim et al. [12] using MDCT corresponded to reversing tumor segments in small homogeneous tumors without a central scar.

We believe that this delayed contrast inversion between the central scar and the peripheral tumor parenchyma observed in oncocytomas is probably due more to the late SI inversion of the central tissue than to the high level of washout of contrast material from the periphery, as reported by Bird et al. [11] because it increased progressively on dynamic images in a centripetal manner.

Rosenkrantz et al. [14] evaluated a series of 28 oncocytomas and 15 chromophobe RCCs, with dynamic contrast-enhanced T1-weighted images that were acquired earlier (no later than 3 minutes after injection). They described their results in a similar manner to our study, using gadolinium-enhanced T1-weighted sequences. However, they did not perform late gadolinium enhancement studies, which are necessary to differentiate oncocytomas from other RCCs.

**Fig. 4---74-year-old woman with renal tumor.**

A, Axial T2-weighted (TR/TE, 2112/100; flip angle, 90°) image shows right renal tumor, slightly hyperintense to renal cortex with well-marked central area of high signal intensity.

B and C, Axial in phase (B) and opposed phase (C) T1-weighted gradient-echo images (TR/TE range, 182/4.8–2.3; flip angle, 70°) show low signal intensity of central area and slight signal intensity drop on opposed phase images with signal intensity index of 24% and tumor-to-spleen ratio of –24%.

D, Dynamic axial T1-weighted fat-suppressed images (TR/TE, 3.9/1.8; flip angle, 10°) obtained 40 seconds (upper left), 2 minutes (upper right), 2.5 minutes (lower left), and 4.10 minutes (lower right) after gadolinium injection show early enhancement of tumor component, with progressive enhancement of scar.

E, Delayed (11 minutes) axial T1-weighted water-select image (TR/TE, 235/5; flip angle, 80°) shows complete enhancement of central area (arrow).

F and G, Macroscopic (F) and microscopic (G) photographs show stellate hemorrhagic central scar (arrow, G) with peripheral edema, few capillaries, and no persistent tumor cells, corresponding to clear cell carcinoma with Fuhrman grade 2.
a segmental SI inversion in 28.6–42.9% of oncocytomas and in 13.3–26.7% of chromophobe RCCs according to each reader. However, no distinction was made in the results between segmental SI inversion within tumor compartments in homogeneous lesions, as defined by Kim et al. [12], and the SI inversion within scars. Moreover, only chromophobe types of RCC were evaluated, whereas our study showed that enhancing fibrous central scars could also be observed in clear cell and papillary RCC.

Renal oncocytomas are composed of two independent components: oncocytic cells and pronounced hyaline and a few fibrotic stromas, which consist of proliferating myofibroblasts with edema and deposition of extracellular matrix (collagen I, collagen III, and fibronectin) [20]. In our series, differences in the degree of SI inversion in central areas of renal masses were related to heterogeneity in vascularization of the tissue and the presence or absence of residual tumor cells. In oncocytomas, enhancing areas corresponded with edematous and fibrohyaline tissue, with poor but preserved cellularity and perfusion, whereas nonenhancing areas corresponded with noncellular and nonperfused hyaline compartments. In carcinomas, enhancing areas corresponded with fibrotic tissue, preserved perfusion without residual tumor cells, and nonenhancing areas due to necrosis, whether hemorrhagic or not.

The microscopic fat content of renal tumors evaluated in vivo with MRI using chemical-shift MRI shows a characteristic signal intensity pattern. A, Axial T2-weighted image (TR/TE, 2112/100; flip angle, 90°) shows left renal tumor isointense to renal cortex with central area of high signal intensity. B and C, Axial in phase (B) and opposed phase (C) T1-weighted gradient-echo images (TR/TE range, 182/4.6–2.3; flip angle, 70°) show variation of signal intensity on whole tumor with signal intensity index of 26% and tumor-to-spleen ratio of −25%. D, Dynamic axial T1-weighted fat-suppressed images (TR/TE, 3.9/1.8; flip angle, 10°) obtained 40 seconds (upper left), 2 minutes (upper right), 2.5 minutes (lower left), and 4.1 minutes (lower right) after gadolinium injection show early enhancement of tumor component, with progressive enhancement of central area except in inner portion. E, Delayed (14 minutes) water-select image (TR/TE, 235/5; flip angle, 80°) shows enhancement appears incomplete, with partial contrast reversal at interface between tumor and central area. Note thin rim of enhancement at junction between tumor and central area components (arrow). F, Macroscopic photograph shows stellate central scar (arrow) corresponding to fibrotic component, with few necrosis and capillaries and without persistent tumor cells. Tumor was identified as clear cell carcinoma with Fuhrman grade 2.

### TABLE 4: Chemical Shift MRI Analysis

<table>
<thead>
<tr>
<th>Chemical Shift MRI</th>
<th>Oncocytoma</th>
<th>Renal Cell Carcinoma</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal intensity index (mean ± SD)</td>
<td>−1.5 ± 9.1 (−19.1 to 11.7)</td>
<td>10.1 ± 15.5 (−19.6 to 50.5)</td>
<td>0.02</td>
</tr>
<tr>
<td>Tumor-to-spleen ratio (mean ± SD)</td>
<td>1.5 ± 11.6 (−15.2 to 20.3)</td>
<td>−14.5 ± 14.2 (−54 to 8.9)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note—Data in parentheses are range.
shift double-echo sequences [19] is typically present in tumor cell cytoplasm in the clear cell subtype of RCC [15, 21] and in spumous histiocytes in papillary RCC [18]. Such content was reported in only one case of a chromophobe RCC [14], but the decrease in SI was assessed only visually. In the same study, none of the oncocytomas showed any signal decrease on opposed phase images. These results support the findings of Krishnan and Truong [22] who noted that only minimal lipid could be detected with electron microscopic examination in oncocytoma and chromophobe RCC. In our study, quantification of SI changes using SI index and tumor-to-spleen ratio showed some overlap between oncocytomas and RCCs and provided cutoff values that, when associated with the analysis of central SI inversion, provided high levels of specificity and NPV.

Our study had some limitations. The first is that the series is retrospective and may have selection bias, as mentioned earlier, explaining the high prevalence of oncocytomas in our series. Second, the sample size is small and this study evaluated only a subset of renal tumors. We did not address oncocytomas or carcinomas with more homogeneous appearance. Third, the SI inversion was assessed qualitatively, although consensus of two experienced radiologists was obtained. Fourth, given the relatively low frequency of oncocytomas, we included MR images acquired over a period longer than 6 years, making the time delay for late MR images quite heterogeneous. Fifth, this was a single institution study, and only one MRI scanner was used. This could flaw the data, especially when calculating precise cutoff values based on MRI-generated signal intensity values as has been proposed.

In summary, according to our results, renal masses presenting with a central heterogeneous area, compatible with a central scar on contrast-enhanced CT or T2-weighted MR images, should be further studied with a delayed (more than 5 minutes) gadolinium-enhanced T1-weighted and a chemical-shift series to better characterize these lesions. Absence of any visual SI inversion of this central area or decrease in SI on opposed phase images should rule out the diagnosis of oncocytoma. In this series, on delayed images all oncocytomas with a scar showed a complete or partial SI inversion, higher than for other areas of the tumor. Some RCCs can also have late-enhancing central areas, but in these cases, some degree of signal drop in opposed phase MR images can assist in the differential diagnosis.

**Acknowledgment**

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**References**


