Original Research Article

# ROLE OF CHEMICAL SHIFT IMAGING IN DETECTING MICROSCOPIC FAT IN ADRENAL AND HEPATIC LESIONS: A CROSS-SECTIONAL STUDY WITH ANATOMICAL AND BIOCHEMICAL CORRELATION

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## ABSTRACT

**Background:** Accurate non-invasive characterization of adrenal and hepatic lesions remains a diagnostic challenge, particularly when lesions appear indeterminate on conventional ultrasonography and computed tomography. Differentiation between benign and malignant lesions is crucial, as it directly influences clinical management and the need for invasive procedures. Chemical shift imaging (CSI) is an established magnetic resonance imaging technique that exploits the precessional frequency difference between fat and water protons, enabling detection of microscopic intracellular fat that may not be appreciable on routine imaging sequences. **Objectives:** To evaluate the diagnostic utility of chemical shift MRI in identifying microscopic fat within adrenal and hepatic lesions, and to assess the correlation of CSI findings with lesion morphology, anatomical characteristics, contrast enhancement patterns, and relevant biochemical parameters.

**Materials and Methods:** This prospective cross-sectional study was conducted over an 18-month period at a tertiary care referral center. A total of 96 patients with indeterminate adrenal ($n = 44$) or hepatic ($n = 52$) lesions detected on prior ultrasonography or CT were included. All patients underwent MRI with in-phase and opposed-phase gradient-echo sequences. Quantitative assessment was performed using signal intensity index and percentage signal loss calculations. Imaging findings were systematically correlated with lesion size, margins, internal architecture, and enhancement characteristics. Biochemical correlation included hormonal assays for adrenal lesions and liver function tests with relevant serum tumor markers for hepatic lesions. Final diagnosis was established based on histopathology where available, or by clinicoradiological follow-up.

**Results:** Significant signal loss on opposed-phase imaging, indicative of microscopic fat, was observed in the majority of benign lesions. Among adrenal lesions, 30 of 34 adenomas (88.2%) demonstrated marked signal drop on opposed-phase sequences, whereas malignant adrenal lesions showed minimal or no signal loss. Similarly, 28 of 31 benign hepatic lesions, including hepatic adenomas and focal fatty lesions (90.3%), exhibited significant signal loss, in contrast to malignant hepatic lesions. The mean percentage signal intensity loss was significantly higher in benign fat-containing lesions compared to malignant lesions ($p < 0.001$). CSI findings showed strong concordance with biochemical profiles, including normal hormonal evaluation in lipid-rich adrenal adenomas and non-elevated tumor markers in benign hepatic lesions. Integration of CSI

with anatomical MRI features improved diagnostic confidence and reduced diagnostic ambiguity.
**Conclusion:** Chemical shift imaging is a reliable, non-invasive MRI technique for detecting microscopic fat in adrenal and hepatic lesions. When combined with detailed anatomical assessment and biochemical correlation, CSI significantly enhances lesion characterization, helps differentiate benign from malignant pathology, and reduces the need for invasive diagnostic procedures. Its routine incorporation into MRI protocols for indeterminate adrenal and hepatic lesions can facilitate accurate diagnosis and optimized patient management.
**Keywords:** Chemical shift imaging; Magnetic resonance imaging; Microscopic fat; Adrenal lesions; Hepatic lesions; Adrenal adenoma; Lesion characterization; Biochemical correlation.

## INTRODUCTION

Accurate characterization of adrenal and hepatic lesions is a common yet critical challenge in daily radiological practice. With the widespread use of ultrasonography and computed tomography, incidental detection of adrenal and liver lesions has increased substantially.[1] While many of these lesions are benign, a significant proportion remain indeterminate on conventional imaging, leading to diagnostic uncertainty, repeated follow-up examinations, or invasive procedures such as biopsy.[2]

Adrenal lesions, particularly adenomas, are frequently encountered incidental findings. Lipid-rich adrenal adenomas can usually be identified on CT by low attenuation values; however, lipid-poor adenomas often overlap in appearance with malignant lesions such as metastases or adrenocortical carcinoma.[3] Similarly, hepatic lesions such as focal fatty infiltration, hepatic adenomas, and well-differentiated hepatocellular carcinoma may show overlapping imaging features on routine sequences, making confident differentiation difficult based on morphology alone.[4]

Magnetic resonance imaging offers superior soft-tissue contrast and multiparametric evaluation, making it an invaluable problem-solving tool for indeterminate lesions. Among MRI techniques, chemical shift imaging plays a pivotal role by exploiting the slight difference in precessional frequencies between fat and water protons.[5] By acquiring in-phase and opposed-phase images, CSI enables detection of microscopic intracellular fat, which is a characteristic feature of several benign adrenal and hepatic lesions and is typically absent or minimal in malignant pathology.[6]

Beyond visual assessment, quantitative analysis using signal intensity index and percentage signal loss has further improved the objectivity and reproducibility of CSI interpretation. These quantitative parameters help reduce inter-observer variability and increase diagnostic confidence, especially in lesions with subtle fat content. However, imaging findings should not be interpreted in isolation, as lesion behavior is closely linked to underlying biochemical and functional characteristics.[7]

Correlation of CSI findings with anatomical features, enhancement patterns, and relevant biochemical markers such as hormonal assays in adrenal lesions and liver function tests or tumor markers in hepatic lesions provides a comprehensive diagnostic framework. Such an integrated approach not only improves lesion characterization but also assists clinicians in determining appropriate management strategies, avoiding unnecessary biopsies or surgeries.[8]

The present study was undertaken to evaluate the role of chemical shift imaging in detecting microscopic fat within adrenal and hepatic lesions and to assess its diagnostic performance when combined with detailed anatomical MRI assessment and biochemical correlation.

## MATERIALS AND METHODS

**Study design**

This study was designed as a prospective cross-sectional observational study aimed at evaluating the diagnostic role of chemical shift MRI in the characterization of indeterminate adrenal and hepatic lesions.

**Study setting and duration**

The study was conducted at a tertiary care teaching hospital over a period of 18 months. Patients referred to the radiology department for further evaluation of adrenal or hepatic lesions detected on prior ultrasonography or computed tomography were screened for inclusion.

**Study population**

A total of 96 patients were included in the study. Of these, 44 patients had adrenal lesions and 52 patients had hepatic lesions. All lesions were considered indeterminate on prior imaging and required further characterization.

**Inclusion criteria**

Patients of either sex and all adult age groups with incidentally detected or clinically suspected adrenal or hepatic lesions on ultrasound or CT were included. Only those patients who underwent MRI with in-phase and opposed-phase sequences and had available biochemical evaluation or follow-up data were enrolled.

**Exclusion criteria**

Patients with known contraindications to MRI, prior surgical or interventional treatment of the lesion, poor image quality due to motion or artifacts, or incomplete biochemical or follow-up data were excluded from the study.

**MRI protocol**

All patients underwent MRI examination using a dedicated body coil. The imaging protocol included axial and coronal T1-weighted and T2-weighted sequences, in-phase and opposed-phase gradient-echo sequences, and contrast-enhanced sequences where clinically indicated. Chemical shift imaging was performed using dual-echo gradient-echo sequences, with in-phase and opposed-phase images acquired during a single breath-hold to minimize motion artifacts.

**Image analysis**

Lesions were evaluated for size, location, margins, internal architecture, signal characteristics, and enhancement pattern. For chemical shift analysis, regions of interest were placed over the lesion on both in-phase and opposed-phase images, avoiding areas of necrosis, hemorrhage, or calcification. Signal intensity index and percentage signal loss were calculated to quantitatively assess microscopic fat content.

**Biochemical correlation**

For adrenal lesions, relevant hormonal assays including cortisol, aldosterone, catecholamines, and other clinically indicated parameters were reviewed. For hepatic lesions, liver function tests and serum tumor markers were analyzed where available. Imaging findings were correlated with biochemical profiles to assess concordance between CSI-detected fat content and functional lesion behavior.

**Reference standard and follow-up**

Final diagnosis was established using histopathological examination when biopsy or surgery was performed. In cases where histopathology was not available, diagnosis was based on clinical, biochemical, and imaging follow-up findings.

**Statistical analysis**

Data were compiled and analyzed using appropriate statistical methods. Quantitative variables were expressed as mean and standard deviation, while categorical variables were expressed as frequencies and percentages. Comparison between benign and malignant lesions was performed using suitable statistical tests, with a p value of less than 0.05 considered statistically significant.

## RESULTS

A total of 96 patients with indeterminate adrenal and hepatic lesions were evaluated using chemical shift MRI during the study period. Of these, 44 patients had adrenal lesions and 52 patients had hepatic lesions. All examinations were technically adequate for qualitative and quantitative chemical shift analysis.

**Distribution and basic characteristics of lesions**

Adrenal lesions were more commonly unilateral, with a slight predominance on the left side. Hepatic lesions were predominantly located in the right lobe. Lesion size varied across both groups, with benign lesions generally demonstrating smaller mean dimensions compared to malignant lesions, although size alone was not a reliable discriminator.

**Chemical shift imaging findings in adrenal lesions**

Among the 44 adrenal lesions, 34 were finally categorized as benign and 10 as malignant based on histopathology or follow-up. Significant signal loss on opposed-phase imaging was observed in the majority of benign adrenal lesions. Thirty out of 34 adrenal adenomas (88.2%) demonstrated marked signal drop, consistent with the presence of microscopic intracellular fat. In contrast, malignant adrenal lesions showed minimal or absent signal loss on opposed-phase images.

Quantitative analysis revealed that the mean signal intensity index and percentage signal loss were significantly higher in benign adrenal lesions compared to malignant lesions. This difference was statistically significant, reinforcing the diagnostic value of CSI in differentiating adrenal adenomas from malignant pathology.

**Chemical shift imaging findings in hepatic lesions**

Of the 52 hepatic lesions evaluated, 31 were classified as benign and 21 as malignant. Benign hepatic lesions, including hepatic adenomas and focal fatty lesions, frequently demonstrated significant signal loss on opposed-phase imaging. Signal drop suggestive of microscopic fat was noted in 28 of 31 benign hepatic lesions (90.3%). Malignant hepatic lesions, including hepatocellular carcinoma and metastatic deposits, largely failed to demonstrate appreciable signal loss.

Quantitative CSI parameters showed a clear separation between benign and malignant hepatic lesions, with benign lesions exhibiting significantly higher mean percentage signal loss. This difference was statistically significant and consistent across lesion subtypes.

**Correlation with anatomical MRI features**

Lesions demonstrating significant signal loss on opposed-phase imaging were more likely to show well-defined margins, homogeneous internal architecture, and benign enhancement patterns. Conversely, lesions without signal loss often exhibited irregular margins, heterogeneous signal intensity, and aggressive enhancement characteristics, supporting malignant etiology.

**Biochemical correlation**

In adrenal lesions, CSI-detected microscopic fat showed strong concordance with biochemical findings. Lipid-rich adrenal adenomas demonstrating signal loss were associated with normal or non-functional hormonal profiles. Malignant adrenal lesions without signal loss were more frequently associated with abnormal biochemical parameters or known primary malignancy.

In hepatic lesions, benign lesions with significant signal loss correlated with relatively preserved liver function tests and non-elevated serum tumor markers. Malignant hepatic lesions, which lacked signal loss on CSI, more commonly demonstrated abnormal liver biochemistry or elevated tumor markers.

**Diagnostic impact of chemical shift imaging**

Incorporation of chemical shift imaging into the MRI evaluation significantly improved diagnostic confidence in both adrenal and hepatic lesions. CSI findings allowed confident characterization of a substantial proportion of lesions as benign, thereby reducing diagnostic ambiguity and limiting the need for invasive biopsy or prolonged imaging follow-up.

**Table 1: Distribution of adrenal and hepatic lesions in the study population**

| Lesion type | Number of patients (n) | Percentage (%) |
|---|---|---|
| Adrenal lesions | 44 | 45.8 |
| Hepatic lesions | 52 | 54.2 |
| Total | 96 | 100.0 |

Table 1 shows the distribution of lesions evaluated in the study, with hepatic lesions slightly more frequent than adrenal lesions.

**Table 2: Final diagnosis of adrenal lesions based on reference standard (n = 44)**

| Adrenal lesion type | Number (n) | Percentage (%) |
|---|---|---|
| Adrenal adenoma | 34 | 77.3 |
| Malignant adrenal lesions | 10 | 22.7 |
| Total | 44 | 100.0 |

Table 2 demonstrates that benign adrenal lesions constituted the majority of cases.

**Table 3: Chemical shift imaging findings in adrenal lesions**

| CSI finding | Adrenal adenomas (n = 34) | Malignant lesions (n = 10) |
|---|---|---|
| Significant signal loss | 30 (88.2%) | 1 (10.0%) |
| Minimal / no signal loss | 4 (11.8%) | 9 (90.0%) |

Table 3 shows the distribution of signal loss on opposed-phase imaging in adrenal lesions.

**Table 4: Quantitative CSI parameters in adrenal lesions**

| Parameter | Benign adrenal lesions (Mean ± SD) | Malignant adrenal lesions (Mean ± SD) | p value |
|---|---|---|---|
| Signal intensity index (%) | 28.6 ± 6.4 | 6.2 ± 3.1 | < 0.001 |
| Percentage signal loss (%) | 31.4 ± 7.2 | 7.1 ± 3.8 | < 0.001 |

Table 4 compares quantitative CSI parameters between benign and malignant adrenal lesions.

**Table 5: Final diagnosis of hepatic lesions based on reference standard (n = 52)**

| Hepatic lesion type | Number (n) | Percentage (%) |
|---|---|---|
| Benign hepatic lesions | 31 | 59.6 |
| Malignant hepatic lesions | 21 | 40.4 |
| Total | 52 | 100.0 |

Table 5 shows that benign hepatic lesions were more frequent than malignant lesions.

**Table 6: Chemical shift imaging findings in hepatic lesions**

| CSI finding | Benign hepatic lesions (n = 31) | Malignant hepatic lesions (n = 21) |
|---|---|---|
| Significant signal loss | 28 (90.3%) | 2 (9.5%) |
| Minimal / no signal loss | 3 (9.7%) | 19 (90.5%) |

Table 6 demonstrates CSI signal loss patterns in hepatic lesions.

**Table 7: Quantitative CSI parameters in hepatic lesions**

| Parameter | Benign hepatic lesions (Mean ± SD) | Malignant hepatic lesions (Mean ± SD) | p value |
|---|---|---|---|
| Signal intensity index (%) | 26.9 ± 5.8 | 5.4 ± 2.9 | < 0.001 |
| Percentage signal loss (%) | 29.7 ± 6.6 | 6.3 ± 3.4 | < 0.001 |

Table 7 compares quantitative CSI measurements between benign and malignant hepatic lesions.

**Table 8: Correlation of CSI findings with biochemical profile**

| Lesion type | CSI signal loss present | Normal biochemical profile | Abnormal biochemical profile |
|---|---|---|---|
| Adrenal lesions | 31 | 28 | 3 |
| Hepatic lesions | 30 | 26 | 4 |

Table 8 shows the concordance between CSI findings and biochemical results.

Table 1 shows that out of 96 patients evaluated, hepatic lesions were observed in 52 patients (54.2%), while adrenal lesions were seen in 44 patients (45.8%), indicating a slightly higher prevalence of hepatic lesions in the study population. Table 2 demonstrates that among the 44 adrenal lesions, benign adrenal adenomas constituted the majority with 34 cases (77.3%), whereas malignant adrenal lesions accounted for 10 cases (22.7%). Table 3 reveals that significant signal loss on opposed-phase imaging was present in 30 out of 34 adrenal adenomas (88.2%), while minimal or no signal loss was noted in 9 of 10 malignant adrenal lesions (90.0%), highlighting a clear distinction between benign and malignant adrenal pathology. Table 4 indicates that benign adrenal lesions showed a higher mean signal intensity index (28.6 ± 6.4%) and percentage signal loss (31.4 ± 7.2%) compared to malignant lesions (6.2 ± 3.1% and 7.1 ± 3.8%, respectively), with the difference being statistically significant. Table 5 shows that among the 52 hepatic lesions, benign hepatic lesions were identified in 31 patients (59.6%), while malignant hepatic lesions were observed in 21 patients (40.4%). Table 6 demonstrates that significant signal loss on chemical shift imaging was seen in 28 of 31 benign hepatic lesions (90.3%), whereas 19 of 21 malignant hepatic lesions (90.5%) showed minimal or no signal loss. Table 7 highlights that benign hepatic lesions exhibited a higher mean signal intensity index (26.9 ± 5.8%) and percentage signal loss (29.7 ± 6.6%) compared to malignant hepatic lesions (5.4 ± 2.9% and 6.3 ± 3.4%, respectively), confirming the diagnostic utility of quantitative CSI parameters. Table 8 demonstrates strong concordance between chemical shift imaging findings and biochemical profiles, with 28 adrenal lesions and 26 hepatic lesions showing both CSI signal loss and normal biochemical parameters, supporting the reliability of CSI in predicting benign lesion behavior.

## DISCUSSION

Accurate differentiation between benign and malignant adrenal and hepatic lesions is essential for guiding appropriate clinical management and avoiding unnecessary invasive procedures. Conventional imaging modalities such as ultrasonography and computed tomography often identify these lesions but may fail to characterize them confidently, particularly when lesions demonstrate indeterminate attenuation or atypical enhancement patterns.[9] The present study highlights the value of chemical shift imaging as a problem-solving MRI technique for detecting microscopic intracellular fat and improving lesion characterization.[10]

In adrenal lesions, the presence of intracellular lipid is a well-recognized feature of adrenal adenomas. While lipid-rich adenomas are easily identified on unenhanced CT, lipid-poor adenomas often overlap with malignant lesions in terms of attenuation values.[11] Chemical shift imaging overcomes this limitation by detecting even small amounts of intracellular fat through signal loss on opposed-phase images.[12] In this study, a high proportion of benign adrenal adenomas demonstrated significant signal loss, whereas malignant lesions consistently lacked this feature. These findings reinforce the role of CSI as a reliable non-invasive tool for distinguishing adrenal adenomas from malignant adrenal pathology.[13]

Similarly, characterization of hepatic lesions poses a diagnostic challenge due to the wide spectrum of benign and malignant entities with overlapping imaging appearances. Benign hepatic lesions such as focal fatty infiltration and hepatic adenomas may contain microscopic fat, which is not always appreciable on routine MRI sequences.[14] The high frequency of signal loss observed in benign hepatic lesions in this study underscores the sensitivity of CSI in detecting intracellular fat. In contrast, malignant hepatic lesions largely failed to demonstrate signal loss, supporting the utility of CSI in narrowing the differential diagnosis when lesion morphology is equivocal.[15]

An important strength of this study is the integration of chemical shift imaging findings with anatomical MRI features and biochemical parameters. Lesions showing significant signal loss were more likely to demonstrate benign morphological characteristics and concordant biochemical profiles, such as normal hormonal assays in adrenal adenomas and non-elevated tumor markers in benign hepatic lesions. This combined approach enhances diagnostic confidence and provides a more comprehensive assessment than imaging or biochemical evaluation alone.[16,17]

Quantitative assessment using signal intensity index and percentage signal loss further strengthened diagnostic accuracy by reducing subjectivity in image interpretation. Quantitative CSI parameters showed a clear and statistically significant distinction between benign and malignant lesions in both adrenal and hepatic groups. Such objective metrics are particularly valuable in borderline cases where visual assessment alone may be inconclusive.[18]

From a clinical perspective, the incorporation of CSI into routine MRI protocols has important implications. Confident identification of benign lesions can reduce the need for invasive biopsies, repeated imaging, or unnecessary surgical interventions. This not only minimizes patient anxiety and procedural risks but also contributes to more cost-effective healthcare delivery.[19]

Despite its strengths, the study has certain limitations. The sample size, particularly for malignant subgroups, was relatively modest. Histopathological confirmation was not available for all lesions, with some diagnoses based on clinical and imaging follow-up. Additionally, chemical shift imaging may be limited in lesions with hemorrhage, calcification, or very small size, which can affect accurate signal measurement.[20]

Overall, the findings of this study support the growing evidence that chemical shift imaging is a robust and reliable MRI technique for detecting microscopic fat and differentiating benign from malignant adrenal and hepatic lesions. When used in conjunction with anatomical imaging and biochemical correlation, CSI provides a comprehensive, non-invasive diagnostic strategy that can significantly influence patient management.

## CONCLUSION

Chemical shift imaging proved to be a valuable and reliable MRI technique for the detection of microscopic intracellular fat in both adrenal and hepatic lesions. In this study, CSI demonstrated a high ability to differentiate benign fat-containing lesions from malignant lesions by identifying significant signal loss on opposed-phase imaging. The clear separation observed between benign and malignant lesions using both qualitative assessment and quantitative parameters such as signal intensity index and percentage signal loss highlights the robustness of this technique.

When CSI findings were interpreted in conjunction with anatomical MRI features and biochemical profiles, diagnostic confidence improved substantially. Benign adrenal and hepatic lesions showing signal loss on CSI were consistently associated with non-aggressive imaging characteristics and concordant normal biochemical parameters, while malignant lesions largely lacked signal loss and were more often associated with abnormal biochemical findings. This integrated approach reduced diagnostic ambiguity and limited the need for invasive procedures such as biopsy.

Overall, routine incorporation of chemical shift imaging into MRI protocols for indeterminate adrenal and hepatic lesions can significantly enhance lesion characterization, support accurate clinical decision-making, and optimize patient management.

**Limitations**

This study has certain limitations that should be considered while interpreting the results. The sample size, particularly within the malignant lesion subgroups, was relatively limited, which may affect the generalizability of the findings. Not all lesions had histopathological confirmation; in several cases, final diagnosis was based on clinical, biochemical, and imaging follow-up, which may introduce a degree of diagnostic uncertainty.

Chemical shift imaging can also be influenced by technical factors such as motion artifacts, partial volume effects, and susceptibility from hemorrhage or calcification, which may affect accurate signal measurement in small or complex lesions. Additionally, very small lesions may not allow precise region-of-interest placement for quantitative analysis. Despite these limitations, the consistent correlation observed between CSI findings, anatomical features, and biochemical profiles supports the clinical utility of this technique.

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