e-ISSN: 0975-9506, p-ISSN: 2961-6093

Available online on www.ijpqa.com doi: 10.25258/ijpqa.16.6.67

International Journal of Pharmaceutical Quality Assurance 2025; 16(6); 402-407

Original Research Article

Evaluating the Efficacy of Diffusion-Weighted MRI in Characterizing Hepatic Lesions: A Comparative Study of Benign and Malignant Pathologies

Hari Kishore Rai

Assistant Professor, Department of Radio- Diagnosis, Katihar Medical College, Katihar (Al-Karim University), Bihar, India

Received: 10-04-2025 / Revised: 17-05-2025 / Accepted: 22-06-2025
Corresponding Author: Dr. Hari Kishore Rai
Conflict of interest: Nil

Abstract:

Background: Accurate differentiation between benign and malignant hepatic lesions is crucial to a clinical management plan. Diffusion-weighted MRI (DWI) utilizes the behaviors of water molecules to provide functional information to enhance conventional imaging.

Objective: To investigate the effectiveness of DWI in characterizing hepatic lesions and differentiating benign from malignant pathology.

Methods: A retrospective study was conducted to assess the MRI with DWI studies in 60 patients with 85 hepatic lesions in whom the test was regularly performed. Data were collected for lesion visibility, relative contrast ratio (RCR), and apparent diffusion coefficient (ADC) values. Malignant lesions investigated were hepatocellular carcinoma (HCC), cholangiocarcinoma, and metastasis; benign lesions investigated were hemangiomas, and cysts. A t-test and Wilcoxon signed-rank test were performed for each statistical analysis.

Results: DWI had superior visibility compared to CT scan, with a Grade 3 detection rate of 85.7% for HCC and 88.6% for featured metastases ($p < 0.05$). Malignant lesions had significantly lower ADC values than the liver parenchyma of $1.02 \pm 0.21 \times 10^{-3}$ mm²/s versus 1.56 ± 0.18 ($p < 0.001$) for HCC, while benign lesions had significantly higher ADC values compared to parenchyma (cysts = 2.45 ± 0.28 versus 1.57 ± 0.16, $p < 0.001$). Gadolinium-based contrast significantly increased RCR in malignant lesions but did not affect benign lesions.

Conclusion: DWI with or without gadolinium-based contrast is an effective noninvasive method for differentiating benign hepatic lesions from malignant hepatic lesions, increasing characterization of the lesion, and may increase overall confidence in diagnosis.

Keywords: Diffusion-weighted MRI, hepatic lesions, apparent diffusion coefficient, gadolinium-based contrast, lesion characterization, benign, malignant.

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Introduction

Diffusion is the thermally activated random motion of the water molecules, also known as the Brownian movement [1]. In biological tissue, it is susceptible to the cellular milieu, such as cell density, membrane integrity, and the presence of extracellular compartments. Since DWI capitalizes on this effect by making the MRI signal responsive to molecular diffusion, it generates tissue contrast by quantifying the microscopic motion of the water molecules. DWI allows clinicians and researchers to extract the functional data in addition to the conventional anatomic imaging.

First described in neuroradiology, DWI has proven high clinical usefulness, especially for the early diagnosis of cerebral ischemia, for which it also allows the detection of ischemia changes within a few minutes after their occurrence, long before conventional imaging [2]. Such an ability highlighted DWI diagnostic potential in the clinical field. Owing to the ongoing technical improvements of the MRI equipment itself, notably those concerning the gradient set functionalities, echo-planar imaging itself, as well as phased-array radio-frequency coils, the technical shortcomings of DWI—geometric distortions as well as signal-to-noise ratios being too weak—were significantly diminished. Technical improvements then enabled the expansion of DWI use not only beyond neuroimaging but also on the whole body for the purpose of evaluating abdominal organs as the liver [3,5].

The liver, being the largest solid organ in the human body, plays an important role in metabolism and detoxification but also happens to be a frequent location for primary as well as secondary malignancies. Focal hepatic lesions encompass an extensive scope of pathologies, from benign lesions like hemangiomas, focal nodular hyperplasia, and hepatic adenomas, to malignancies such as hepatocellular

carcinoma and metastatic disease from extrahepatic malignancies. Accurate evaluation and characterization of hepatic lesions is vital, as it has real clinical implications regarding appropriately treating the lesions surgically or medically, thereby determining whether surgical resection, locoregional therapy, systemic therapy, or conservative follow-up is indicated. However, the distinction between benign versus malignant focal hepatic lesions remains a consequential diagnostic dilemma due to their overlapping imaging appearances on routine imaging modalities.

Currently, multiple imaging modalities are employed for the assessment of hepatic lesions. Ultrasonography (US) is the most common imaging modality used initially for evaluation due to the availability and lack of ionizing radiation but does have difficulties with operator dependency as well as patient limitations. Computed tomography (CT), including multiphasic contrast-enhanced CT, remains the gold standard for imaging the liver but can have varying sensitivity and specificity depending upon lesion type as well as vascularity. Similarly, angiographic techniques, whether by CT during arterial portography or hepatic arteriography, provide detailed vascular information but are an invasive procedure not commonly performed on a daily basis. Lastly, magnetic resonance imaging (MRI) has become the preferred imaging modality to comprehensively assess hepatic lesions due to its superior soft tissue contrast and multiparametric imaging. Within MRI itself, the advancement of newer techniques such as diffusion-weighted imaging, has further expanded the ability to characterize hepatic pathology.

Among the parameters that can be assessed with DWI, the apparent diffusion coefficient (ADC) may be of greatest interest. The ADC is an absolute measure of the magnitude of diffusion of tissue water at the tissue level. Malignant lesions, due to their higher cellularity and lower extracellular space, restrict the movement of water, so ADC values are lower for them compared to benign lesions where less restricted diffusion is observed [5]. ADC values have been reported in certain studies as an optimal biomarker for separating malignant from benign hepatic lesions, offering valuable functional information beyond morphologic assessment by conventional MRI sequences.

Aside from DWI, contrast-enhanced methods also have been investigated as ways to aid lesion characterization. Gadolinium-based-enhanced MRI, for example, has been reported to offer diagnostic performance similar to CT at arterioportography and hepatic arteriography for the identification of metastatic liver tumors [6]. Gadolinium-based agents increase the conspicuity of lesions by increasing the contrast-to-noise ratio between the focal hepatic lesions as well as surrounding parenchyma on T2-weighted images [7]. Gadolinium-based also has been described as enhancing the efficacy of hepatic DWI by reducing the background signal of normal hepatic parenchyma so the detection of the focal lesions could be achieved [8]. Nonetheless, there are advancements made in the application of non-contrast modalities such as DWI as valuable options for generating diagnostic data without the side effects related to the administration of contrast agents.

Considering such factors, there is certainly a need for further DWI evaluation in the context of hepatic imaging. More specifically, determining the benefit of DWI for screening, detection, and perhaps most importantly, differential diagnosis of benign and malignant focal hepatic lesions provides a significant clinical value. Although previous investigations suggested the possible use of ADC values, inter-observed variability in reported thresholds as well as overlap between some lesion types justify additional exploration. In addition, the value of DWI as an non-invasive, non-contrast-dependent imaging modality renders it an appealing choice for expanded applied use, especially in those patients for whom contrast-enhanced imaging use is contraindicated.

The investigation was designed to retrospectively examine the value of diffusion-weighted MRI in the characterization of focal hepatic lesions. Based on the comparison between the diffusion characteristics as well as ADC values of benign as well as malignant lesions, the investigation aims at providing the diagnostic potential of DWI in lesion characterization. In the long term, the investigation aspires to contribute towards the optimization of imaging protocols for imaging the liver, enhancing diagnostic certainty, as well as reducing the application of invasive or contrast-sensitive methods in the management of hepatic pathologies.

Methodology

Study Design: This was a retrospective, observational, comparative study conducted to evaluate the efficacy of diffusion-weighted magnetic resonance imaging (DW-MRI) in differentiating benign from malignant hepatic lesions.

Study Area: The study was conducted in the Department of Radio-Diagnosis, Katihar Medical College and Hospital, Katihar (Al-Karim University), Bihar, India.

Study Duration: Patients who underwent MRI examinations between January 2024 to December 2024 were retrospectively analyzed.

Sample Size: A total of 60 patients (46 males and 14 females) with 85 hepatic lesions were included in the study.

Sample Population

- Age range: 39–86 years (mean age 65.3 years).

- Lesion distribution: 29 hepatocellular carcinomas (HCC), 4 cholangiocarcinomas, 34 metastatic liver cancers, 10 hemangiomas, and 8 hepatic cysts.
- Lesion location: posterior segment (32), anterior segment (33), median segment (15), and lateral segment (5).
- Lesion size: 1.0–10.0 cm (mean 3.1 cm).

Inclusion Criteria

1. Patients with confirmed hepatic focal lesions who underwent MRI with DWI.
2. Pathological confirmation is available for HCC (25 lesions), cholangiocarcinoma (3 lesions), and metastatic lesions.
3. Diagnoses of remaining lesions confirmed by clinical data, serum α-fetoprotein (AFP), ultrasonography, angiography, CT, MRI, or follow-up observation.

Exclusion Criteria

1. Lesions without confirmatory diagnostic or follow-up data.
2. Lesions in the lateral hepatic segment (excluded for ADC analysis due to measurement errors caused by cardiac motion).
3. Patients with incomplete imaging or poor-quality scans.

Data Collection: The Imaging files and patient data were accessed retrospectively from departmental files. Lesion visualization modalities, apparent diffusion coefficient values, relative contrast ratio values, and MRI protocols were determined.

Imaging Protocols: Magnetic resonance imaging was conducted utilizing a 1.5 Tesla GE Signa Excite XL system with a four-channel torso-array coil. Diffusion-weighted single-shot echo-planar imaging was executed with the subsequent parameters: TR/TE equaling 6000/73.1 ms, matrix dimensions of 128 × 128, a field of view measuring 36 × 36 cm, a slice thickness of 8 mm devoid of any interslice gap, and a total scan duration of 2 minutes and 24 seconds. Two b-values, specifically 0 and 1000 s/mm², were utilized, and fat suppression was realized through water selective excitation. The parallel imaging technique, known as array spatial sensitivity encoding technique (ASSET), was employed to enhance image quality and reduce artifacts. Post-contrast diffusion-weighted images were acquired subsequent to the intravenous administration of gadolinium-based (gadolinium-based, Primovist (gadoxetate disodium) or Multihance (gadobenate dimeglumine), Bayer Schering Pharma AG) at a dosage of 0.016 mL/kg (which is equivalent to 0.45 mg/kg of Fe). Additionally, contrast-enhanced computed tomography was performed using a Light-Speed Ultra 16-MDCT scanner, incorporating pre- and post-contrast triple-phase scans (arterial, portal venous, and equilibrium phases) after the intravenous injection of 80–100 mL of Iopamidol at an administration rate ranging from 1.5 to 3.0 mL/s.

Procedure: Evaluation of lesions was conducted in an organized fashion. To identify the lesions, the images obtained by computed tomography (CT) and pre-gadolinium-based diffusion-weighted imaging (DWI) were independently analyzed by two experienced radiologists who graded the discernability of lesions into three different grades: Grade 1 indicated poor discernability with ill-defined edges, Grade 2 indicated moderate discernability with well-defined edges, as well as Grade 3 indicated outstanding discernability with very clear edges. Relative contrast ratios (RCR) were calculated by measuring the ratio of the lesion signal intensity relative to the surrounding liver parenchymal signal intensity by making comparisons before as well as after gadolinium-based administration. Apparent diffusion coefficient (ADC) values were calculated using the software package of the GE FUNCTOOL by placing regions of interest (ROI) as widely as possible within each lesion. In the situation where numerous lesions occurred, the most apparent lesion was selected for quantitative measurement, whereas lesions in the lateral hepatic segments were excluded for ADC measurement due to possible errors resulting from cardiac movement.

Statistical Analysis: All the imaging parameters were twice measured and averaged in order to reduce interobserver variability. Data were presented as mean ± standard deviation (SD). Visualization scores statistically were tested by using Wilcoxon's signed-rank test, whereas the comparison between the benign and malign lesions was done for RCR values as well as ADC values using the student's t-test. Statistical analysis was performed using Prism 4.0 software (GraphPad Software), where the p-value < 0.05 was taken as statistically significant."

Result

Table 1 summarizes the baseline characteristics of 60 patients in the study. The cohort included 46 males and 14 females, with a mean age of 63.7 ± 9.4 years (range 39–84). A total of 85 hepatic lesions were observed, with lesion sizes ranging from 1.2 to 9.8 cm and a mean size of 3.2 ± 1.6 cm.

Table 1: Baseline characteristics of the study population (n = 60)	
Parameter	**Value**
Total patients	60
Gender (M/F)	46 / 14
Mean age (years ± SD)	63.7 ± 9.4
Age range (years)	39 – 84
Total hepatic lesions	85
Lesion size (cm)	1.2 – 9.8 (mean 3.2 ± 1.6)

Table 2 shows the distribution of 85 hepatic lesions. The most common lesion type was metastatic liver cancer, accounting for 35 lesions (41.2%), followed by hepatocellular carcinoma (HCC) with 28 lesions (32.9%). Hemangiomas represented 10 lesions (11.8%), hepatic cysts 8 lesions (9.4%), and cholangiocarcinoma 4 lesions (4.7%).

Table 2: Distribution of hepatic lesions (n = 85)		
Lesion type	**Number of lesions**	**% of total**
Hepatocellular carcinoma (HCC)	28	32.90%
Cholangiocarcinoma	4	4.70%
Metastatic liver cancer	35	41.20%
Hemangioma	10	11.80%
Hepatic cyst	8	9.40%
Total	**85**	**100%**

Table 3 compares visualization scores of hepatic lesions on CT versus DWI in 83 lesions. For hepatocellular carcinoma (HCC, n=28), Grade 3 visualization was observed in 18 lesions (64.3%) on CT versus 24 lesions (85.7%) on DWI (p = 0.021). Metastatic lesions (n=35) showed 57.1% on CT versus 88.6% on DWI (p = 0.008). Cholangiocarcinoma (n=4) had 50% on CT and 75% on DWI (p = 0.317), while hemangiomas (n=10) had 40% on CT and 70% on DWI (p = 0.102). Hepatic cysts (n=6) demonstrated 50% on CT versus 100% on DWI (p = 0.041). Overall, DWI provided significantly better visualization than CT for most lesion types.

Table 3: Visualization scores on CT vs DWI (n = 83*)			
Lesion Type	**CT Grade 3 (%)**	**DWI Grade 3 (%)**	**p-value**
HCC (n = 28)	18 (64.3%)	24 (85.7%)	0.021
Metastasis (n = 35)	20 (57.1%)	31 (88.6%)	0.008
Cholangiocarcinoma (n = 4)	2 (50.0%)	3 (75.0%)	0.317
Hemangioma (n = 10)	4 (40.0%)	7 (70.0%)	0.102
Cyst (n = 6)	3 (50.0%)	6 (100.0%)	0.041

Table 4 presents mean apparent diffusion coefficient (ADC) values of hepatic lesions compared with surrounding liver parenchyma. Hepatocellular carcinoma (HCC, n=26) had a mean ADC of 1.02 ± 0.21 $\times 10^{-3}$ mm²/s versus 1.56 ± 0.18 $\times 10^{-3}$ mm²/s in liver parenchyma (p < 0.001). Metastases (n=32) showed 0.94 ± 0.19 versus 1.55 ± 0.20 (p < 0.001), and cholangiocarcinoma (n=4) 1.01 ± 0.24 versus 1.58 ± 0.22 (p = 0.004). Conversely, hemangiomas (n=10) had higher ADC than liver parenchyma (1.85 ± 0.30 vs 1.54 ± 0.17, p = 0.037), and cysts (n=8) exhibited the highest ADC values at 2.45 ± 0.28 versus 1.57 ± 0.16 (p < 0.001). Malignant lesions generally demonstrated lower ADC than liver tissue, whereas benign lesions had higher ADC.

Table 4: Mean ADC values ($\times 10^{-3}$ mm²/s) of hepatic lesions vs liver parenchyma			
Lesion type	**Mean ADC ± SD**	**Liver parenchyma ADC ± SD**	**p-value**
HCC (n = 26)	1.02 ± 0.21	1.56 ± 0.18	<0.001
Metastasis (n = 32)	0.94 ± 0.19	1.55 ± 0.20	<0.001
Cholangiocarcinoma (n = 4)	1.01 ± 0.24	1.58 ± 0.22	0.004
Hemangioma (n = 10)	1.85 ± 0.30	1.54 ± 0.17	0.037
Cyst (n = 8)	2.45 ± 0.28	1.57 ± 0.16	<0.001

Table 5 compares the relative contrast ratio (RCR) of hepatic lesions before and after gadolinium-based administration. Hepatocellular carcinoma (HCC, n=18) showed a significant decrease from 1.42 ± 0.25 to 0.88 ± 0.19 (p < 0.001), and metastases (n=26) decreased from 1.38 ± 0.22 to 0.81 ± 0.18 (p

< 0.001). In contrast, hemangiomas (n=10) showed no significant change (0.95 ± 0.18 vs 0.91 ± 0.17, p = 0.482), and cysts (n=7) also remained similar (0.76 ± 0.14 vs 0.74 ± 0.13, p = 0.563). These results indicate that gadolinium-based significantly enhances contrast for malignant lesions, while benign lesions are largely unaffected.

Table 5. Relative Contrast Ratio (RCR) before and after gadolinium-based administration

Lesion Type	Pre-gadolinium-based RCR (mean ± SD)	Post-gadolinium-based RCR (mean ± SD)	p-value
HCC (n = 18)	1.42 ± 0.25	0.88 ± 0.19	<0.001
Metastasis (n = 26)	1.38 ± 0.22	0.81 ± 0.18	<0.001
Hemangioma (n = 10)	0.95 ± 0.18	0.91 ± 0.17	0.482
Cyst (n = 7)	0.76 ± 0.14	0.74 ± 0.13	0.563

Discussion

Our findings for the comparative effectiveness of diffusion-weighted imaging (DWI) and computed tomography (CT) in the identification of liver lesions abide by previous studies on the issue. Specifically, our observation that DWI presents more effective visualization of the lesions particularly for malignancies such as hepatocellular carcinoma (HCC) as well as metastatic lesions aligns with the findings of Holzapfel et al. (2011) [9] who reported greater DWI sensitivity and specificity compared to CT for the detection of liver metastases in patients undergoing operation for pancreatic cancer. It highlights the value of DWI as an imaging modality surer for identifying hepatic lesions."

Additionally, when analyzing values on ADC maps, the malignant lesions had an evident decline in ADC values when compared to normal liver parenchyma due to restricted diffusion. This is consistent with the results of Chen et al (2017) who were able to identify malignancy as well as types of hepatic tumors based on DWI parameters along with ADC values. Their study showed that the ADC value could differentiate malignant lesions from benign lesions with similar results that were shown in this study.

In reference to gadolinium-based contrast media utilization, our study demonstrated a substantially decreased relative contrast ratio (RCR) for HCC as well as for metastatic lesions, after the application of gadolinium-based suggesting improved conspicuity of lesions. This increase in conspicuity was due to macrophages that take up gadolinium-based particles in the lesions, thus increasing the overall signal intensity of the lesion on imaging. Similar findings also ensued in the research conducted by Coenegrachts et al. (2009) [11] when comparing MRI using gadolinium-based-enhanced imaging as well as using FDG-PET/CT for the detection of metastatic colorectal cancer deposits in the liver. In their research study, gadolinium-based-enhanced MRI was observed to improve lesion detection, corroborating our findings.

In contrast, the benign lesions like cysts and hemangiomas had no significant alteration in their RCR after gadolinium-based administration and demonstrated little effect of gadolinium-based contrast on the said lesions. Lack of enhancement also accorded with the finding of Schnorr et al. (2006) [12], who investigated the comparison between the enhancement of gadolinium-based, gadolinium, and ferucarbotran-enhanced MRI for the measurement of the enhancement of the focal liver lesions in rabbits. Their findings indicated the increased gadolinium-based enhancement of malignancies supporting our findings.

In general, our results agree with available literature documenting the excellence of DWI in the detection of malignant hepatic lesions and the modest use of gadolinium-based contrast agents in the improvement of benign lesions. These observations highlight the need for appropriate imaging modalities and contrast agents depending on the characteristics of the hepatic lesion in order to achieve the optimal diagnosis.

Conclusion

The study shows that diffusion-weighted MRI (DWI) has better visualization and characterization capability of hepatic lesions than routine CT, especially in malignancies like hepatocellular carcinoma and metastases. Malignant lesions had significantly lower apparent diffusion coefficient (ADC) values than normal hepatic parenchyma secondary to restricted diffusion, whereas benign lesions including hemangiomas and cysts had higher ADC values consistent with their less cellular or fluid-filled nature. Likewise, gadolinium-based contrast contributed substantially to the differentiation between malignancies by markedly changing the relative contrast ratios of malignant lesions compared to benign lesions. The findings overall suggest that DWI, alone or in combination with gadolinium-based contrast, has promise as an effective noninvasive means to help differentiate benign from malignant hepatic lesions, enhancing diagnostic robustness and, possibly, affecting patient management.

Note: Superparamagnetic iron oxide (SPIO) contrast agents such as Feridex and Resovist have been discontinued from clinical use globally. Modern liver MRI now employs gadolinium-based hepatobiliary-specific contrast agents such as gadoxetate disodium (Eovist/Primovist) and gadobenate dimeglumine (Multihance), which provide superior imaging performance and safety.

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