ORIGINAL RESEARCH

Diffusion Weighted MRI in Evaluation of Focal Liver Lesions

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ABSTRACT

Background: The present study was undertaken to determine the role of noncontrast MRI and diffusion weighted imaging in particular along with the corresponding ADC values in the identification and characterization of the focal liver lesions. The study proposes to set forth a cut off ADC value for quickly differentiating between benign and malignant hepatic focal lesions.

Materials and Methods: 70 patients who were referred to our department with strong clinical suspicion of focal liver lesion and those diagnosed by ultrasonography followed by multiphasic contrast enhanced CT underwent non-contrast Magnetic Resonance Imaging evaluation of abdomen using 1.5 T 8 channel MRI. The MRI scans were then reviewed and various focal liver lesions were identified.

Results: The MRI and DWI picked up more focal lesions compared to both USG and Multiphasic CT alone. Ultrasonography shows a sensitivity of 73% though its specificity was a good 88% in predicting malignancy. Multi phasicCT shows a sensitivity of 88% and specificity of 93% in differentiating benign from malignant focal lesion. DWI and ADC values have very good sensitivity and NPV of 97% and 98% respectively for malignant focal liver lesions. The drop in specificity and PPV of ADC values when compared to combined MRI findings of 93% and 91% is mainly due to the low ADC values obtained for abscess. A cut off ADC value of 1.4 x 10-3 mm2/s is considered for differentiating benign from malignant lesions. Difference in mean ADC values of malignant and nonmalignant lesions is highly significant.[P=0.00001].

Conclusion: The sensitivity of noncontrast MRI with DWI and ADC values was very high and more than both USG and contrast enhanced Multiphasic CT. The specificity of MRI was comparable to that of CE- Multiphasic CT in diagnosing malignant focal liver lesions. A cut off ADC value of 1.4 x 10-3 mm2/s was found to be a superior, noninvasive tool for differentiating malignant from benign lesions without the risk of radiation, contrast media and invasiveness. Hence, MRI with DWI in particular is a very valuable noninvasive tool for the identification and characterization of focal liver lesions.

Keywords: Hepatic tumor, Liver imaging, Magnetic resonance imaging, Apparent Diffusion Coefficient (ADC), Diffusion weighted imaging (DWI).

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INTRODUCTION

MRI is a competitive and comprehensive modality for assessing the morphology and functional characteristics of the liver in cases of diffuse and focal liver disease. Technical improvements, such as the development of more powerful gradient systems and phased-array body coils, as well as the implementation of advanced imaging sequence designs, such as respiratory triggered three-dimensional data acquisition and sparse k-space sampling schemes, permit high-quality examination of the liver with both T1- and T2- weighted pulse sequences. Based on recent advances in MRI technique, diffusion-weighted imaging (DWI) has been applied to liver examinations. Diffusion weighted imaging (DWI) is another mechanism for developing image contrast and relies on changes in the diffusion properties of water molecules in tissues. DWI is a widely accepted technique in neuroradiology for detecting early ischemia in cerebrovascular accidents and characterization of brain tumors and intracranial infection. The use of DWI in other parts of the body is relatively new, but very promising for the detection and differentiation of benign and malignant lesions, imaging for dissemination (i.e. staging) in oncological patients before treatment and for follow-up after treatment of liver tumors. Besides this, DWI is thought to be capable of predicting the response to therapy of malignant tumors (especially chemotherapy). Diffusion is expressed in an apparent diffusion coefficient (ADC), which reflects the diffusion properties unique to each type of tissue. With assessment of ADC values, DWI proved to be helpful in characterization of focal liver lesions. However, DWI should always be used in conjunction to conventional MRI since there is considerable overlap between ADC values of benign and malignant lesions. In addition, DWI is a promising tool in the prediction of tumor responsiveness to chemotherapy and the follow-up of oncological patients after treatment, as DWI may be capable of detecting recurrent disease earlier than conventional imaging. This study is aimed at determining the role of Diffusion weighted MR imaging of liver in the detection and characterization of focal liver lesions and using their ADC values to differentiate benign from malignant lesions and to compare the results obtained with the previously done studies. Though MDCT has been a robust imaging technique for liver pathologies, it includes the use of contrast agent and exposure to radiation. Diffusion weighted MR imaging provides for a tool to characterize focal liver lesions without the risk of contrast agents and exposure to ionizing radiation. In addition, DW MRI and dynamic MRI are more sensitive in picking sub centimeter lesions and in characterizing heterogeneous equivocal lesions on MDCT. DWI is also thought to be capable of predicting the response to therapy of malignant tumors.

MATERIALS & METHODS

This prospective study was done in the Department of Radiodiagnosis Chirayu Medical College Bhopal and Department of Radiodiagnosis L.N. Medical College Bhopal India. A total of 70 patients who were referred to department with strong clinical suspicion of focal lesion of liver lesion were diagnosed by ultrasonography underwent triphasic contrast enhanced CT evaluation of abdomen followed by magnetic resonance imaging evaluation of abdomen, from January 2021 to December 2021.

Patient selection

Inclusion criteria

- Patients referred to the Department of Radiodiagnosis Chirayu Medical College Bhopal and Department of Radiodiagnosis L.N. Medical College Bhopal with strong clinical suspicion of focal lesion of liver including those with primary malignancy elsewhere.
- Patients already diagnosed with focal liver lesion by ultrasonography.
- Patients with equivocal findings on contrast enhanced CT examinations.

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Exclusion criteria

- Patients with mass lesions infiltrating the liver from outside the liver.
- Patients with traumatic injury to liver.
- Severely ill patients who couldn‘t maintain adequate breath hold.
- Patients with general contraindication to MRI such as those with pace makers, cochlear implants and other electromagnetic implants in body.

Instrumentation

MRI examination was performed on 1.5 Tesla MR System; this is a high field strength superconducting magnet, with a cylindrical configuration. A 8 channel high resolution coil dedicated QD body array coil was used for imaging the liver.

Study Protocol

A detailed history of the patient including signs and symptoms, detailed physical examination, biochemical investigations and radiological investigations which included chest x-ray and ultrasonography of the abdomen were recorded and tabulated as in the proforma shown.It was made sure that the patient doesn‘t have any contraindication for MRI scanning and is not in possession of any metallic objects.

The patient was then placed on the gantry table in supine position with arms placed above the head. Patient was explained to hold his/her breath on verbal instruction and to resume breathing on reinstruction. In case patient was dyspnoeic or was unable to hold breath for reasonably long time, he/she was advised to maintain shallow breathing.

Pulse Sequences & Imaging Planes

Analysis of ADC is an automated process, available as an application on our scanner. Calculation of ADC is made for each voxel of an image and is displayed as a parametric (ADC) map. ADC measurements are then recorded for a given region by drawing regions of interest (ROIs) on the ADC map.

The magnetic resonance scans were reviewed and findings were recoded in proforma.The liver was viewed in T1W, T2W and DWI sequences with calculation of ADC values using the ADC maps and any abnormality was identified. When multiple lesions are noted the most representative lesion or the largest of the lesions was taken into consideration. When different types of lesions were identified in the same person representative lesions of each type was considered.

The following characteristics of the lesions were noted:

- The number of lesions
- The segmental location of the lesion
- The size and shape of the lesion
- The presence of septa/ internal nodules
- The wall/ thickness of wall/sharpness of contour
- Homogenous/heterogenous
- Appearance on diffusion weighted images and in corresponding ADC maps
- Regions of interest (round shape, at least 10 mm in diameter) were placed on the focal liver lesions on the ADC map to obtain a mean ADC value in mm2/sec.
- Other specific features

All the results were tabulated in a proforma. Follow up of all patients was done either with biopsy, aspiration, surgical correlation, and follow up ultrasonography to look for the stability of the lesion, additional investigations like CECT/nuclear scintigraphy. The final diagnosis is made. Then results obtained are compared with the Diffusion weighted imaging findings along with the mean ADC values of the specific focal liver lesions and tabulated.

Consent

Written consent was obtained from the relatives of patients after explaining them the nature and purpose of the study. They were assured that confidentiality would be strictly maintained. The option to withdraw from the study was always open.

RESULTS

This prospective study was done in the Radiodiagnosis Department, Chirayu Medical College & L.N. Medical College Hospital and Research Centre, Bhopal, M.P. India. A total of 100 lesions in 70 patients who were referred to department with strong clinical suspicion of focal lesion of liver lesion underwent ultrasonography & triphasic contrast enhanced CT evaluation of abdomen followed by magnetic resonance imaging evaluation of abdomen, from Jan 2021 to Dec 2021.

Table 1: Presenting Complaints

Complaints	Number	Percentage
Pain	32	46
H/O Malignancy	25	36
Mass Abdomen	17	24
Incidental	22	31
Jaundice	18	26
Fever	14	20
Vomiting	11	16
Total	70	100

Table 2: Laterality of Lesion

Laterality of lesions	N	%
Right Lobe	43	43
Left Lobe	19	19
Both Lobes	38	38
Total	100	100

Table 3: Segmental Location of Lesions

Segment	Number	Percentage
I	0	0
II	12	12
III	14	14
IV	25	25
V	31	31
VI	22	22
VII	25	25
VIII	30	30

Table 4: Accuracy of USG in Predicting Malignancy

USG	Follow up		
	Malignant	Non-malignant	Total
Malignant	30	7	37
Non-malignant	11	52	63
Total	41	59	100

Table 5: Accuracy of Triple Phase CT in Predicting Malignancy

Triple Phase CT	Follow up		
	Malignant	Non-malignant	Total
Malignant	36	4	40
Non-malignant	5	55	60
Total	41	59	100

Table 6A: MRI Features of Inflammatory Lesions

Lesions	T1WI	T2WI	DWI	Wall	Septations
Abscess	Hypo-Intense	Hyperintense	Hyperintense	Irregular Ill Defined	Present
Hydatid Cyst	Hypo-Intense	Hyperintense	Hypo-Intense	Well Defined	Membranes
Hepatic Granuloma	Hypo-Intense	Hyperintense/ Isoint ense	Isointense	Ill Defined	Absent

Table 6B: MRI Features of Benign Lesions

Lesions	T1WI	T2WI	DWI	Wall	Septations
Hepatic Cyst	Hypo- Intense	Hyperintense	Hypo-Intense	Well Defined	Absent
Hemangioma	Hypo- Intense	Hyperintense	Hypo-Intense	Well Defined	Present
Focal Nodular Hyperplasia	Hypo to Isointense	Hyperintense	Isointense to Liver	Well Defined	Central Scar
Hepatic Adenoma	Hyper to Isointense	Hypo to Isointense	Hyperint ense	Well Defined	Central Scar
Focal Fat Sparing	Inphase- Hypo & Relatively Hyper In Opposed Phase	Iso Intense	Isointense	Well Defined	Absent

Table 6C: MRI Features of Malignant Lesions

Lesions	T1WI	T2WI	DWI	Wall	Septations
Hepato Cellularcarcinoma	Hypo Inte Nse	Hyper Inte Nse	Hyper Inte Nse	Well Defined	Vascul Ar Chanel S
Fibrolamel Ler Carcinoma	Hypo Inte Nse	Hyper Inte Nse	Hyper Inte Nse	Well Defined	Centra L Scar
Metastasis	Hypo Inte Nse	Hyper Inte Nse	Hyperinte Nse	Ill Defin Ed	Absent Bull'S Eye Patter N'

Table 7: Accuracy of ADC Values in Predicting Malignancy

ADC	Follow up		
	Malignant	Non-malignant	Total
Malignant	40	8	48
Non-malignant	1	51	52
Total	41	59	100

Table 8: Calculation of P Value Comparing ADC Value of Malignant and Nonmalignant Lesions

ADC Values	Malignant	Nonmalignant
N	41	57
mean	0.89 x $\mathbf{10^{-3}}$ m$\boldsymbol{m^2/s^2}$	2.36 x $\mathbf{10^{-3}}$ m$\boldsymbol{m^2/s^2}$
SD	0.089 x $\mathbf{10^{-3}}$ m$\boldsymbol{m^2/s^2}$	0.66 x $\mathbf{10^{-3}}$ m$\boldsymbol{m^2/s^2}$
P value	0.00001 HS	

Table 9: Accuracy of MRI +ADC in Predicting Malignancy

MRI + ADC	Follow up		
	Malignant	Non-malignant	Total
Malignant	40	4	44
Non-malignant	1	55	56
Total	41	59	100

Table 10: Follow Up Findings

Type of Lesion	USG	Triple Phase CT	ADC values	Conventional MRI+ADC	Follow up
Inflammatory	12	8	2	6	6
Benign	41	48	50	50	53
Malignant	37	40	48	44	41
Total	90	96	100	100	100

Majority of patients in our study group belonged to the age group 40-49 years (34%) with mean age of 46.3 years. In our study, the majority of patients were males constituting 64 % cases. Majority of patients presented with complaint of pain abdomen (46%), followed by H/O of malignancy which was 36% of total patients.31% of cases in the study also showed some incidentally detected focal lesion in the liver.41 % of focal liver lesions present were identified as benign in ultrasonography examination. Only 90% of the total lesions were identified initially by USG.

48 of focal liver lesions present were identified as benign in Multi phasic CT examination. 96% of the total lesions were picked up by Multi phasic CT. Focal lesions were most common in the right lobe of liver with 43% lesions. 38% of lesions were found to be situated in both lobes. Focal lesions were most common in the segment V of liver with 31% lesions, followed by segment VIII. A majority of the lesions identified in MR imaging were found to be multiple, constituting 59% of the total lesions. Most of the focal lesions encountered were in the 2.1 –3 cms range(23%) with a mean of 2.7 cm.26 patients had cirrhotic liver with superimposed focal liver lesion.

44 patients had a focal liver lesion in normal liver parenchyma.50 % of focal liver lesions present were identified as benign in MRI examination. MRI identified 10% more lesions than USG and 4% more focal lesions than Multiphasic CT examination. Abscess was the most common inflammatory lesion constituting 4% of the total focal liver lesions. Inflammatory lesions constituted only 6% of total focal liver lesions primarily because they were not frequently referred for further MRI examination. Hemangioma constituting 29% was the most common focal lesion of liver, both benign and malignant. Only 2% of lesions turned out to be FNH. Metastasis formed the most common malignant focal hepatic lesion in liver constituting 27% of total lesions. Ascites was by far the commonest associated finding that was identified. The ADC value of cirrhotic liver parenchyma is less than that of the normal liver parenchyma. Benign lesions generally have an ADC value of >2 x 10-3 mm2/s.

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Malignant lesions generally have an ADC value of <1 x 10-3 mm2/s. The MRI and DWI picked up more focal lesions compared to both USG and Multiphasic CT alone. Ultrasonography shows a sensitivity of 73% though its specificity was a good 88% in predicting malignancy. Multi phasic CT shows a sensitivity of 88% and specificity of 93% in differentiating benign from malignant focal lesion. DWI and ADC values have very good sensitivity and NPV of 97% and 98% respectively for malignant focal liver lesions. The drop in specificity and PPV of ADC values when compared to combined MRI findings of 93% and 91% is mainly due to the low ADC values obtained for abscess. A cut off ADC value of 1.4 x 10-3 mm2/s is considered for differentiating benign from malignant lesions. Difference in mean ADC values of malignant and nonmalignant lesions is highly significant.[P=0.00001].

Statistical Analysis

The collected data was summarized by using frequency, percentage, mean & S.D. To compare the qualitative outcome measures Chi-square test or Fisher’s exact test was used. To compare the quantitative outcome measures Independent t test was used. If data was not following normal distribution, Mann Whitney U test was used. SPSS version 22 software was used to analyse the collected data. p value of <0.05 was considered to be statistically significant

DISCUSSION

Diffusion-weighted imaging (DWI) plays an emerging role for the assessment of focal and diffuse liver diseases. This growing interest is due to that fact that DWI is a noncontrast technique with inherent high contrast resolution, with promising results for detection and characterization of focal liver lesions. Recent advances in diffusion image quality have also added interest to this technique in the abdomen.

The liver was viewed in T1W, T2W and DWI sequences with calculation of ADC values using the ADC maps and any abnormality was identified. When multiple lesions are noted the most representative lesion or the largest of the lesions was taken into consideration. When different types of lesions were identified in the same person representative lesions of each type was considered. The following characteristics of the lesions were noted. A cut off ADC value of 1.4 x 10-3 mm2/s is considered for differentiating benign from malignant lesions.

Focal liver lesions (FLL’s) are encountered on a daily basis in general radiology practice. Usually lesions can be accurately characterised on unenhanced ultrasound. If not, many patients proceed to computed tomography (CT) or magnetic resonance imaging (MRI) with the main aim to determine benign from malignant conditions. Focal liver lesions are usually detected incidentally during abdominal ultrasound. The injection of microbubble ultrasound contrast agents improves the characterization of focal liver lesions that are indeterminate on conventional ultrasound. The use of CEUS is recommended in official guidelines and suggested as a second diagnostic step after ultrasound detection of indeterminate focal liver lesions to immediately establish the diagnosis, especially for benign liver lesions, such as hemangiomas, avoiding further and more expensive examinations.[1]

Fawkes A et al studied contrast enhanced ultrasound v’s contrast enhanced MRI/CT in the characterisation of focal liver lesions using an evidence based approach. CEUS involves the use of microbubble contrast agents (e.g SonoVue) and specialized imaging. Evidence suggests CEUS has a high sensitivity and specificity in the characterisation of focal liver lesions. Provides accurate diagnostic information comparable to CECT and CEMRI.

The purpose of this study by Semelka RC et al was to compare dual-phase spiral computed tomography (CT) and magnetic resonance imaging (MRI) using dynamic gadolinium enhancement for liver lesion detection and characterization. Patients underwent dual-phase spiral CT and MRI for the evaluation of focal liver disease within a 1-month period. Spiral CT and MR images were interpreted prospectively, in a blinded fashion by separate, individual, experienced investigators, to determine lesion detection and characterization. More lesions were characterized on MR images in 41% patients. In patients with a discrepancy between MR and CT findings, the MR images added information considered significant to patient management in all cases. MRI was moderately superior to dual-phase spiral CT for lesion detection, and was markedly superior for lesion characterization, with these differences having clinical significance.

Various authors have elaborated the role of magnetic resonance diffusion imaging in differentiation of malignant and benign hepatic focal lesions. Li J et al studied clinical study of diffusion-weighted imaging in the diagnosis of liver focal lesion. Their aim was to determine whether the DW-MRI can be used for qualitative and quantitative liver cancer analysis, where an automated method will be proposed for improving the accuracy of liver segmentation in DW-MRI to increase the ability of diagnosis of disease. Their result from the liver DW-MRI image is quantitatively and qualitatively analyzed. Experimental results show that DW-MRI has a great advantage in the diagnosis, the DWI images of benign lesion group was lower than that of malignant lesion, thus DW-MRI is segmented by graph-cut algorithm can provide important additional information regarding differential diagnosis of specific liver cancer to some extent.

Koike N et al did similar study on the role of diffusion-weighted magnetic resonance imaging in the differential diagnosis of focal hepatic lesions. Visualization of lesions, relative contrast ratio (RCR), and apparent diffusion coefficient (ADC) were compared between benign and malignant lesions on DWI. Superparamagnetic iron oxide (SPIO) was administered to 59 patients, and RCR was compared pre- and post-administration. RCR between malignant lesions and surrounding hepatic tissues significantly improved after SPIO administration, but RCRs in benign lesions were not improved. It was concluded that DWI is a simple and sensitive method for screening focal hepatic lesions and is useful for differential diagnosis.

Chiu FY et al assessed whether administration of gadolinium-based contrast material significantly affects DWI and ADC values at the focal hepatic lesions. The statistical significance of differences between precontrast and postcontrast administration was determined by use of a paired t test. They concluded that there was no significant difference before and after administration of contrast agent in the SNR or CNR of DWI. This indicates the feasibility of postcontrast DWI as a substitute for an unsuccessful precontrast-enhanced study in clinical practice.

Jeon SK et al also investigated added value of MRI to preoperative staging MDCT for evaluation of focal liver lesions (FLLs) in potentially resectable pancreatic ductal adenocarcinomas (PDACs).Size of hepatic lesions was measured and detection rate of hepatic metastasis unsuspected by MDCT and diagnostic yield of MRI for FLLs were assessed. In potentially resectable PDACs, addition of MRI with DWI can provide significantly better diagnostic performance in characterization of focal liver lesions, especially for small-sized (≤ 1 cm) MDCT-indeterminate or suspicious metastasis lesions, aiding in determination of appropriate operation candidates.

The purpose of this review by Galea N et al is to describe the current clinical roles of DWI for the detection and characterization of focal liver lesions, and to review pitfalls, limitations, and future directions of DWI for assessment of focal liver disease. Whereas Sandrasegaran K et determined if focal liver masses could be differentiated as benign or malignant on the basis of diffusion-weighted imaging (DWI). DWI was performed with b values of 0, 50, and 400 s/mm2. Of 104, 76 patients had lesions larger than 2 cm diameter, radiologic or pathologic characterization of the lesion, and diagnostic quality DWI. The apparent diffusion coefficient (ADC) of the largest liver lesion was measured. The liver masses were diagnosed on histology or had characteristic computed tomography/MRI findings and follow up of more than 6 months. The ADC of cysts and hemangiomas were significantly higher than that of other lesions (P = .0003, t-test). There was no significant difference between ADC values of solid, benign liver lesions (FNH, adenoma) and malignant lesions (HCC, metastases) (P =.62). To conclude, solid liver lesions have a lower ADC than cysts and hemangiomas. However, there is no significant difference in ADC between solid benign and malignant lesions. DWI appears to have only minimal additional value over currently used MRI sequences in characterizing liver masses

Parikh T et al retrospectively compare diffusion-weighted (DW) magnetic resonance (MR) imaging with standard breath-hold T2-weighted MR imaging for focal liver lesion (FLL) detection and characterization, by using consensus evaluation and other findings as the reference standard. Reference standard for diagnosis was obtained from consensus review by the two observers of DW, T2-weighted, and dynamic contrast material–enhanced images, pathologic data, and follow-up imaging results. Apparent diffusion coefficient (ADC) was measured for FLLs identified at consensus review.They concluded that DW MR imaging was better than standard breath-hold T2-weighted imaging for FLL detection and was equal to breath-hold T2-weighted imaging for FLL characterization.

CONCLUSION

Thus, the sensitivity of non-contrast MRI with DWI and ADC values was very high and more than both USG and contrast enhanced Multiphasic CT. The specificity of MRI was comparable to that of CE- Multiphasic CT in diagnosing malignant focal liver lesions. A cut off ADC value of 1.4 x 10-3 mm2/s was found to be a superior, noninvasive tool for differentiating malignant from benign lesions without the risk of radiation, contrast media and invasiveness. Hence, MRI with DWI in particular is a very valuable noninvasive tool for the identification and characterization of focal liver lesions.

REFERENCES

1. Lencioni R, Cioni D, Bartolozzi C. Focal liver lesions. Detection, characterization, ablation/R. Lencioni, D. Cioni, C. Bartolozzi.–2005.–284 p. 2005.
2. Marrero JA, Ahn J, Reddy RK, Practice Parameters Committee of the American College of Gastroenterology. ACG clinical guideline: the diagnosis and management of focal liver lesions. Official journal of the American College of Gastroenterology| ACG. 2014 Sep 1;109(9):1328-47.
3. D'Onofrio M, Crosara S, De Robertis R, Canestrini S, Mucelli RP. Contrast-enhanced ultrasound of focal liver lesions. American journal of roentgenology. 2015 Jul;205(1):W56-66.
4. Fawkes A, Malone DE. Contrast enhanced ultrasound V’s contrast enhanced MRI/CT in the characterisation of focal liver lesions using an evidence based approach. European Congress of Radiology-ECR 2015.
5. van Leeuwen MS, Noordzij J, Feldberg MA, Hennipman AH, Doornewaard H. Focal liver lesions: characterization with triphasic spiral CT. Radiology. 1996 Nov;201(2):327-36.
6. Matos AP, Velloni F, Ramalho M, AlObaidy M, Rajapaksha A, Semelka RC. Focal liver lesions: Practical magnetic resonance imaging approach. World journal of hepatology. 2015 Aug 8;7(16):1987.
7. Semelka RC, Martin DR, Balci C, Lance T. Focal liver lesions: comparison of dual-phase CT and multisequence multiplanar MR imaging including dynamic gadolinium enhancement. Journal of Magnetic Resonance Imaging: An Official Journal of the International Society for Magnetic Resonance in Medicine. 2001 Mar;13(3):397-401.
8. Kumaraswamy S, Kaur A, Kaur N, Walia HM, Bains R, Abraham J. Role of Magnetic Resonance Diffusion Imaging in Differentiation of Malignant and Benign Hepatic Focal Lesions.

9. Li J, Yang Y. Clinical study of diffusion-weighted imaging in the diagnosis of liver focal lesion. Journal of Medical Systems. 2019 Mar;43(3):1-7.
10. Koike N, Cho A, Nasu K, Seto K, Nagaya S, Ohshima Y, Ohkohchi N. Role of diffusion-weighted magnetic resonance imaging in the differential diagnosis of focal hepatic lesions. World journal of gastroenterology: WJG. 2009 Dec 12;15(46):5805.
11. Chiu FY, Jao JC, Chen CY, Liu GC, Jaw TS, Chiou YY, Hsu FO, Hsu JS. Effect of intravenous gadolinium-DTPA on diffusion-weighted magnetic resonance images for evaluation of focal hepatic lesions. Journal of computer assisted tomography. 2005 Mar 1;29(2):176-80.
12. Jeon SK, Lee JM, Joo I, Lee DH, Ahn SJ, Woo H, Lee MS, Jang JY, Han JK. Magnetic resonance with diffusion-weighted imaging improves assessment of focal liver lesions in patients with potentially resectable pancreatic cancer on CT. European radiology. 2018 Aug;28(8):3484-93.
13. Galea N, Cantisani V, Taouli B. Liver lesion detection and characterization: role of diffusion- weighted imaging. Journal of magnetic resonance imaging. 2013 Jun;37(6):1260-76.
14. Sandrasegaran K, Akisik FM, Lin C, Tahir B, Rajan J, Aisen AM. The value of diffusion-weighted imaging in characterizing focal liver masses. Academic radiology. 2009 Oct 1;16(10):1208-14.
15. Parikh T, Drew SJ, Lee VS, Wong S, Hecht EM, Babb JS, Taouli B. Focal liver lesion detection and characterization with diffusion-weighted MR imaging: comparison with standard breath-hold T2-weighted imaging. Radiology. 2008 Mar;246(3):812-22.