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Diagnostic Performance of Multiparametric MRI in Characterizing Adrenal Lesions

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Abstract

Background: Adrenal nodules are common incidental findings in radiological daily routine with lipid-rich adenomas are the most frequent. Sometimes lipid-poor adenomas may not be fully characterized on CT or chemical shift imaging (CSI). These indeterminate lesions pose management dilemmas particularly in patients with known primary malignancy.

Aim of Study: The aim of this study was to evaluate the diagnostic performance of mutliparametric MRI in characterization of adrenal lesions, with particular regard to the distinction between adenomasand malignant tumors.

Material and Methods: Forty patients with 42 adrenal lesions underwent multiparametric MRI including conventional MRI, CSI, diffusion weighted imaging (DWI), diffusion tensor imaging (DTI, in 12 patients) and dynamic contrast enhanced (DCE) MRI. Imaging features on conventional MRI were evaluated, CSI was assessed both qualitatively and quantitatively by calculating the adrenal signal intensity index (ASII), apparent diffusion coefficient (ADC) and fractional anisotropy (FA) values of the lesions were measured and enhancement pattern on DCE-MRI was assessed both qualitatively and quantitatively. Statistical analysis was performed.

Results: Most adenomas displayediso- to low signal intensity (SI) on T2-weighted images (WI), while most non-adenomas exhibited heterogeneous high T2-SI.A significant signal drop on CSI was seen in most of adenomas. ASII exhibited high statistically significant difference (p=0.01) in differentiating adenomas from non-adenomas, at acut off value of 23% the sensitivity was 92% and the specificity was78%. On DWI, ADC valuescould not show significant statistical difference between adenomas and non-adenomas. On the other hand, FA values measured on DTI revealed high statistically significant difference in differentiating adenomas from non-adenomas (p=0.01). In receiver operating characteristics (ROC) curve analysis, FA cut off value 0.34 gave 100% sensitivity and 84% specificity. As regard DCE-MRI, most adenomas exhibited homogeneous enhancement, whereas most adrenocortical carcinomas (ACC) and metastases showed heterogeneous or peripheral enhancement. Quantitative assessment of dynamic curve including time to peak (TTP) enhancement showed high statistically significant difference in differentiating adenomas from non-adenomas (p=0.01), a cut off value 43 seconds gave 100% sensitivity and 60% specificity.

Conclusions: Multiparametric MRI including conventional imaging, CSI, DWI, DTI as well as DCE-MRI is helpful in characterizing adrenal lesions with increased diagnostic confidence.

Key Words: *Adrenal lesions – Adenomas – Non-adenomas – Multiparametric MRI.*

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List of Abbreviations:

CSI : Chemical shift imaging.
DWI : Diffusion weighted imaging.
DTI : Diffusion tensor imaging.
DCE : Dynamic contrast enhanced.
ASII : Adrenal signal intensity index.
ADC : Apparent diffusion coefficient.
FA : Fractional anisotropy.
SI : Signal intensity.
WI : Weighted image.
ROC : Receiver operating characteristics.
ACC : Adrenal cortical carcinoma.
TTP : Time to peak.
PCC : Pheochromocytoma.
HU : Hounsfield unit.
OP : Out-phase.
IP : In-phase.
TR : Repetition time.
TE : Echo time.
FOV : Field of view.
ROI : Region of interest.
AUC : Area under the curve.
CI : Confidence interval.

Introduction

ADRENAL lesions are heterogeneous group of conditions with variable clinical presentation and prognosis. Most adrenal lesions are benign; about 70% are adenomas and 20% other benign lesions [ex. Myelolipoma, hyperplasia and pheochromocytoma (PCC)]. The remaining 10% are malignant lesionsincluding metastasis and more rarely, adrenocortical carcinoma (ACC), primary adrenal lymphoma, sarcoma or malignant PCC ***[1,2]***.

Incidental adrenal nodules are common clinical scenario seen in approximately 5% of abdominal CT examinations in patients with no history of malignancy or endocrine abnormality. The incidence rises up to 9%-13% in patients with known malignancy ***[3-5]***. Most incidental adrenal lesions are non-functioning benign adenomas. However, metastasis, ACC and PCC can also be found incidentally. In patients with known history of malignancy, accurate characterization of adrenal lesions is crucial for accurate staging, directing therapy and predicting prognosis of the primary disease. Also it can preclude the need for biopsy, surgery and follow-up imaging in these patients ***[6-8]***.

Unenhanced CT is commonly the first imaging modality for adrenal lesion characterization based on the presence of intracellular lipids. About 70% of adrenal adenomas are lipid-rich and attenuation values <10 Hounsfield unit (HU) are diagnostic indicators. Up to 30% of adrenal adenomas are lipid-poor having attenuation values >10 HU and may be misdiagnosed as malignant. In cases of uncertain diagnosis, a multiphasic acquisition protocol is required ***[9,10]***.

Early and delayed phases contrast enhanced CT are important for lipid-poor adenoma diagnosis. It can differentiate adrenal adenomas from non-adenomas since adrenal adenomas demonstrate early arterial enhancement and washout. Exposure to ionizing radiation, the need for iodinated contrast and multiple phases that may impact the work flow are the main limitations of CT. Also, complex image interpretation with the need to calculate several quantitative parameters. Finally, misdiagnosis of PCC and hypervascular metastases (ex. hepatocellular and renal cell carcinomas) that may exhibit washout pattern similar to adenomas ***[11-14]***. Although CT is the cornerstone of adrenal imaging, the diagnosis may be challenging for atypical lesions. A multimodality multiparametric and functional imaging approach can help increase confidence in characterizing adrenal lesions and avoid useless biopsy or surgery ***[15]***.

MRI is the second-line imaging modality for adrenal lesion characterization. Adrenal lesions with unenhanced CT attenuation values between 10 and 30 HU can be characterized by MRI when iodinated contrast material injection and calculation of washout ratios cannot be performed. The role of MRI in characterizing adrenal lesions has evolved tremendously in the last years due to absence of ionizing radiation, its inherent tissue characterizing ability and variety of pulse sequences that add to the diagnostic accuracy ***[16]***.

Chemical shift imaging (CSI) has become the mainstay for differentiation of adenomas from non-adenomas based on the presence of intra-cytoplasmic lipid in most adenomas in contrast to other adrenal lesions ***[17-20]***. On CSI, the loss of signal intensity (SI) on out-phase (OP) when compared with in-phase (IP) images depends on the lower precession frequency of fat protons compared to water protons. The concentration of fat and water protons are equivalent in lipid-rich adenomas, so there is almost complete SI loss on OP images. While in lipid-poor adenomas, there is no change of SI on OP imaging. The value of CSI is limited in metastases from primary malignancies that have intracellular fat (renal cell and hepatocellular carcinomas) that show signal drop on OP images. This also may be seen in some ACCs and PCCs ***[13,21-23]***.

Previous research has demonstrated the value of early dynamic gadolinium-enhanced evaluation. Most adrenal adenomas, regardless of their lipid content, show an immediate homogeneous capillary blush and rapid fading in contrast to most of malignant lesions ***[24]***. Though the diagnostic value of dynamic contrast enhanced (DCE) MRI alone is lower than CSI, signal intensity-time curve parameters [contrast enhancement, time to peak (TTP) and wash-in rates] may contribute to the results of CSI and improves the diagnostic capabilities in atypical cases ***[18,22,25,26]***.

It is reported that diffusion weighted imaging (DWI) has limited ability in differentiating between benign and malignant adrenal lesions because of significant overlap in quantitative apparent diffusion coefficient (ADC) values ***[27,28]***. As regard-diffusion tensor imaging (DTI), to our knowledge, there is shortagein previous studies assessing its role in characterizing adrenal lesions.

The aim of this study:

Was to evaluate the diagnostic performance of multiparametric MRI including CSI, DWI, DTI and DCE-MRI incharacterizing adrenal lesions.

Patients and Methods

This prospective study was carried on 40 patients with adrenal lesions detected either incidentally on US, CT or MRI or in patients with known adrenal lesions. They were referred from Urology outpatient clinic and examined at the Radiology department in the period from April 2018 to July 2022.

All patients were subjected to clinical assessment, laboratory investigations and multiparametric

MRI including conventional imaging, CSI, DWI, DTI (in 12 patients) as well as DCE-MRI. The final diagnosis of the lesions was confirmed by either histopathology (after surgery or biopsy) or clinical and radiological follow-up. The study was approved by our institutional review board of ethics and informed consent was obtained from all patients.

Inclusion criteria:

1- Patients' agreement to join the study according to the ethical considerations.
2- Patients having adrenal lesion detected either by ultrasound, CT or MRI.
3- Male and female patients.
4- All age groups.

Exclusion criteria:

1- Patients with severe claustrophobia.
2- Patients with metallic devices (ex. cardiac pacemaker, aneurysmal clip, cochlear implant).
3- Patients with no pathological proof or regular follow-up.

MRI technique:

All patients were examined in supine position using 3-Tesla MRI scanner (Phillips, Ingenia, the Netherlands). Each patient was subjected tomultiparametric MRI of the abdomen including the following:

T1-WI: Repetition time (TR)/echo time (TE) 425/15 msec, field of view (FOV) 390mm, slice thickness 3mm, inter-slice gap 0.4 mm and matrix 288 × 192. T1-WIs were obtained in axial plane.

T2-WI: TR/TE 5000/120msec, FOV 390mm, slice thickness 3mm, inter-slice gap 0.4mm and matrix 288 × 192. T2-WIs were obtained in axial, sagittal and coronal planes.

CSI: It is a refocused dual gradient echo sequence using fast field echo with the following parameters: TR 130 msec, double TEs of 4.5 and 2.3 msecused for OP and IP images respectively, flip angle 80, FOV 390 mm, 3 mm slice thickness, 0.3 mminter-slice gap, matrix 256 x 192 and number of echoes = 2.

DWI: Was done during free breathing with axial plane fat suppressed water excited single shot spin echo and variable bvalues (b100,800,1000 s/mm^2), TR 2500-5300msec, TE 61msec, flip angle 90 degree, FOV 300mm, matrix 128 × 128, slice thickness 3-4mm, inter-slice gap 0.3-0.4mm and number of excitations 4-10. The ADC maps were generated from DWI using specialized software.

Additional DTI was performed (in 12 cases): With single shot echo planar imaging, TR10000 msec, TE 70 msec, FOV 300 mm, matrix 100×132, slice thickness 3mm, no inter-slice gap, SENSE factor 2 and bvalue 0-400 s/mm^2. Fractional anisotropy (FA) maps were generated by the specialized software.

DCE-MRI: Was done by administratingGadopentetatedimeglumine (Magnevist, Bayer Schering Pharma) using automatic injector at a dose of 0.1 mmol/kg of body weight at a rate of 1.5-2ml/s followed by saline flush. Imaging was done using fat-suppressed 3D volumetric spoiled gradient echo sequence in axial, sagittal and coronal planes at 30 s after injection and repeated 4-6 times every 30 s. TR 3.8msec, TE 1.2msec, flip angle 15 degree, FOV 270mm, matrix 192 × 192, slice thickness 1mm, no inter-slice gap and number of excitations 1.

Image analysis:

The MR images were uploaded to the workstation provided by the vendor and were reviewed and processed for all adrenal lesions as follows:

1- Non-contrast morphologic criteria and SI of the lesion including the size and T2-SI.

2- CSI evaluation including qualitative and quantitative methods: In qualitative method, the SI of the lesion at OP images relative to that at IP images was visually evaluated in which 0 = no significant signal loss, 1 = significant loss. While in quantitative analysis, region of interest (ROI) was placed in the center of the solid part of the lesion in both IP and OP imagesto obtain SI measurements. ROI was placed to cover enough region more than half of the lesion avoiding its most peripheral component to avoid partial volume effect from the adjacent fat. Additionally, blood vessels, calcification, as well as cystic and necrotic areas were excluded. Then, the percentage of signal drop is calculated using adrenal signal intensity index (ASII) equation:

ASII = (SI In Phase – SI Out Phase)/(SI In Phase) X 100

3- DWI: ADC measurements were done automatically on ADC maps. ROIs were placed manually on the lesions. In order to cover the entire lesion, the ROI area was kept as large as the adrenal lesion avoiding necrotic, calcified or cystic areas. The ADC values were expressed as mean ± standard deviation mm^2/s.

4- DTI: FA measurements were performed on color-coded FA maps. ROIs were manually positioned on the solid component of the lesion.

5- DCE-MRI evaluation: Was performed using qualitative and quantitative methods. The qualitative enhancement pattern was classified into 5 categories: Homogeneous, punctate, heterogeneous, peripheral, and negligible. "Homogeneous enhancement" means a uniform increase in the SI. "Punctate enhancement" describes an enhancement in which SI increases with small punctuate foci of lesser SI. "Heterogeneous enhancement" refers to an enhancement in which irregular portions of the lesion demonstrate lesser SI. "Peripheral enhancement" is an enhancement in whichSI increases in

the peripheral part of the lesion only. “Negligible enhancement” means no apparent enhancement.

In quantitative method; evaluationwas done automatically by placing a ROI in the most enhancing part of the lesion, generating signal intensity-time curves with calculation of TTP, maximum relative enhancement, wash-in rate and wash-out of contrast.

Statistical analysis:

Data were arranged, coded then analyzed by using the statistics computer program SPSS (Statistical package for social science) version 28. The sensitivity and specificity of different MRI parameters were calculated to differentiate non-adenomatous lesions from adenomas at different cutoff points using receiver operating characteristic (ROC) curve analysis to define the best cut-off point along with the diagnostic performance of each test. The *p*-values were determined using Chi-square test. A *p*-value <0.05 is considered statistically significant and <0.01 is highly significant.

Results

Our study included 40 patients (22 men, 18 women) with 42 adrenal lesions. These 42 lesions included: 14 adenomas (~33.3%), and 28 non-adenomas (~66.7%) distributed as follows: 8 ACCs (19%), 8 metastases (19%), 5 PCCs (11.9%), 3 myelplipomas (7.1%), 2 ganglioneuromas (4.8%), one cyst (2.4%) and one adrenal hemorrhage (2.4%). Two patients had bilateral lesions (bilateral adenomas in one patient, and bilateral metastases in another patient). The age of the patients ranged from 5-64 years. The final diagnosis of the lesions was confirmed by either histopathology (after surgery or biopsy) or clinical and radiological follow-up withregular MRI examinations.

Analysis of adrenal lesions diameter revealed that most adenomas (12 out of 14) were <5cm, while the other 2 adenomas measured >5cm. In non-adenomas (28 lesions) the size was variable, where 21 lesions were >5cm and the other 7 lesions were <5cm. Out of 8 metastases, 5 masses were >5cm while 3 masses were <5cm. In ACCs, all 8 masses were >5cm. In myelolipomas, PCCs, cyst and hemorrhage the size was variable, which suggests that size measurement could be helpful in differentiating adenomas from malignant lesions.

As regard signal characteristics on T2-WI, 10 adenomas hadiso- to low SI (71.4 %), 2 adenomas appeared of high SI (14.3%) and the remaining 2 adenomas appeared heterogeneously hyper-intense (14.3%). On the other hand, only 2 of the ACCs (25%) had iso- to low T2-SI, while the other 6 ACCs (75%) appeared with high or heterogeneously high SI. As regard 8 metastatic lesions, one lesion (12.5%) showed is to low SI and 7 lesions (87.5%) were heterogeneously hyper-intense. As regard PCCs, 4 out of 5 lesions (80%) had high T2-SIand single lesion (20%) appeared heterogeneously high. The 3 included myelolipomas and the 2 ganglioneuromas appeared of high or heterogeneously high SI. Also, the cyst and hemorrhage appeared of high T2-SI.

As regard CSI, results of qualitative analysis of the signal loss on OP images were as follows: Of the 14 adenomas, 12 (85.7%) showed significant signal loss and 2 (14.3%) showed no remarkable signal loss. In comparison, none of the ACCs or PCCs showed signal loss. Also, only one of the 8 metastatic lesions showed signal loss. A significant statistical difference with *p*-value=0.01 was found between adenomas and non-adenomas. Results of the qualitative analysis of the signal loss in OP images for different adrenal lesions are shown in (Table 1).

Table (1): The qualitative analysis of the signal loss on out-phase CSI in different adrenal lesions.

	Chemical shift MRI			*p*-value
	No drop	Drop	Total	
Adenoma	2	12	14	0.01
ACC	8	0	8	
Metastasis	7	1	8	
PCC	5	0	5	
Myelolipoma	0	3	3	
Ganglioneuroma	2	0	2	
Cyst	1	0	1	
Hemorrhage	1	0	1	
Total	26	16	42	

Quantitative analysis was done using ASII and revealed statistically significant difference between adenomas and non-adenomas (*p*-value = 0.01). Also, statistically significant difference was noted between adenomas and ACCs (*p*-value = 0.01), adenomas and metastases (*p*-value = 0.001) and between adenomas and PCCs (*p*-value = 0.004). However no significant difference could be noted when comparing metastases to ACCs to PCCs (*p*-value = 0.73). The values of ASII of different adrenal lesions are shown in (Table 2).

Table (2): ASII of different adrenal lesions.

	ASII %			*p*-value
	Minimum	Maximum	Mean	
Adenoma	22	83	63	0.01
Non Adenoma	5	54	21	
ACC	14	54	23	
Metastasis	5	36	19	0.73
PCC	12	32	21	

In ROC curve analysis of ASII in differentiating adenomas from non-adenomas, area under the curve (AUC) was 0.954, at a cut off value of 23% the sensitivity was 92% and the specificity was 78% (Fig. 1).

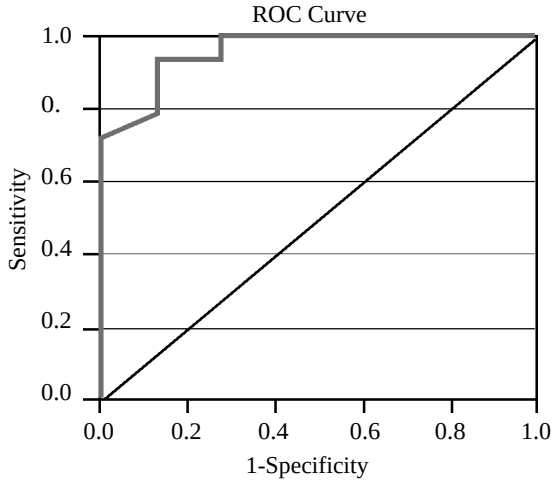

Fig. (1): ROC curve analysis of sensitivity and specificity of ASII in differentiation between adenomas and non-adenomas.

As regard DWI, this study revealed that ADC values of adenomas were slightly higher than non-adenomatous lesions, however this difference did not reach statistical significance (*p*-value =0.174). In ROC curve analysis for differentiating adenomas from non-adenomas, AUC was 0.680. The mean ADC value for adenomas was 1.4±0.22 x 10-3mm^2/s while the mean ADC value for non-adenomas was 1.2±0.24 x 10-3mm^2/s.

DTI with measurement of FA values was performed only in 12 lesions (5 adenomas, and 7 non-adenomas including 4 ACCs, metastasis from bronchogenic carcinoma, metastasis from renal cell carcinoma and metastasis from hepatocellular carcinoma). This study revealed that FA values of adenomas were significantly higher than non-adenomas (*p*-value=0.01). The mean FA value for adenomas was 0.46 compared to 0.33 for non-adenomas. In ROC curve analysis of FA in differentiation of adenomas from non-adenomas, AUC was 0.958, in which at FA cut off value 0.34, the sensitivity was 100% and the specificity was 84% (Fig. 2).

As regard pattern of enhancement at CE-MRI,-most adenomas (8 out of 14) showed homogenous enhancement. In contrasts 5 out of 8 ACCs showed heterogeneous enhancement and 4 out of 8 metastatic lesions showed peripheral enhancement pattern. This revealed statistically significant difference (*p*-value=0.02). The detailed qualitative visual enhancement pattern of the lesions is shown in (Table 3).

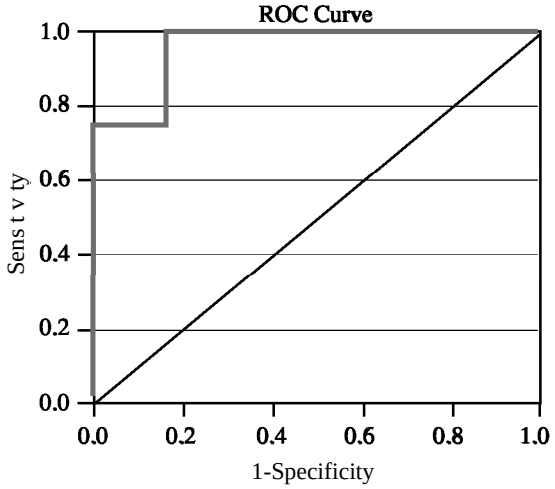

Fig. (2): ROC curve analysis of FA in differentiation between adenomas and non-adenomas.

Table (3): Contrast enhancement patterns of different adrenal lesions.

	Homoge-nous	Punct-ate	Heterog-eneous	Periphe-ral	Negligi-ble	Total	*p*-value
Adenoma	8	4	1	0	1	14	0.02
ACC	1	1	5	1	0	8	
Metastasis	1	0	2	4	1	8	
PCC	2	0	3	0	0	5	
Myelolipoma	1	0	2	0	0	3	
Ganglioneuroma	1	0	1	0	0	2	
Cyst	0	0	0	0	1	1	
Hemorrhage	0	0	0	0	1	1	

Quantitative evaluation on DCE-MRI was done automatically on the work-station after generation of SI-time curves with calculation of TTP and wash-in rate. The peak enhancement of malignant adrenal lesions were slightly higher than adenomas, however this did not reach any statistical significance. In terms of TTP enhancement, adenomas had significantly lower TTP than non-adenomas (adenomas 40-69 seconds, mean 50 sec, while non-adenomas 55-167 seconds, mean 107sec) with *p*-value = 0.01. On the other hand, no statistically significant difference could be obtained when comparing TTP values of ACCs, metastases and PCCs with *p*-value = 0.25 (Table 4).

Table (4): TTP enhancement of ACCs, Metastases and PCCs.

	TTP			*p*-value
	Minimum	Maximum	Mean	
ACC	69	146	94	0.25
Metastasis	55	105	75	
PCC	61	167	117	

In ROC curve analysis of TTP in differentiation of adenomas from non-adenomas, AUC was 0.929 with 95% confidence interval (CI) in which cut off value of 43 seconds giving sensitivity of 100% and specificityof 60% (Fig. 3).

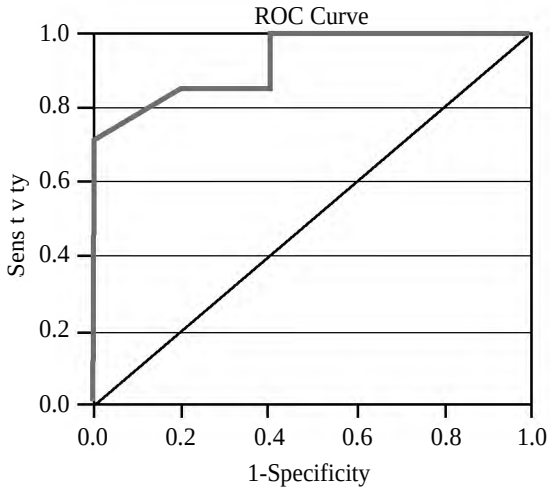

Fig. (3): ROC curve analysis of TTP in differentiation between adenomas and non-adenomas.

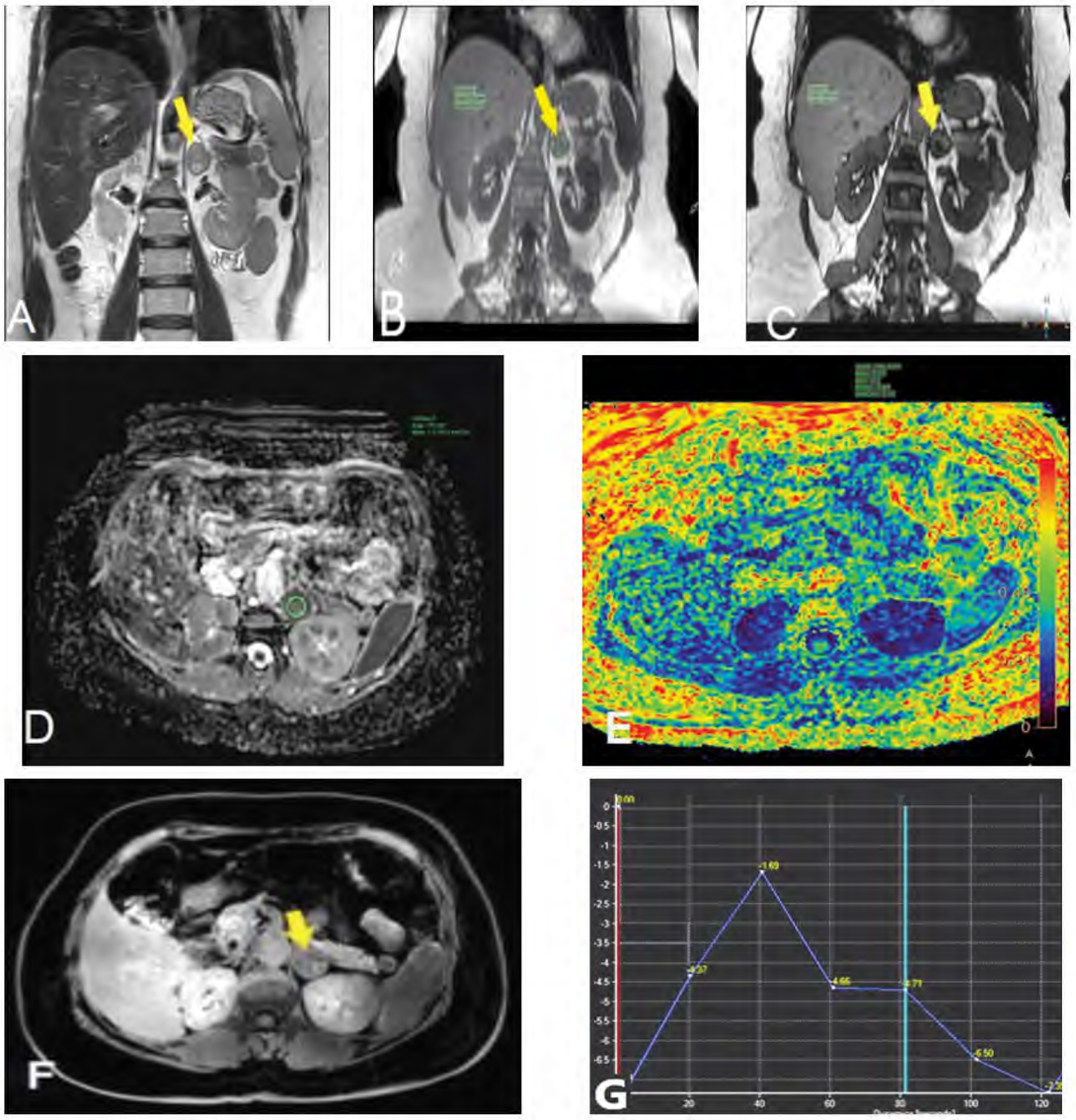

Fig. (4): Case of adenoma in 55years old patient with incidentally discovered left adrenal lesion. [A] Coronal T2-WI revealed left adrenal lesion showing iso-intense SI. [B, C] IP and OP images revealed signal drop of the lesion in OP with ASII = 66%. [D] ADC map: the lesion show low signal on ADC with mean ADC value =1.2 x 10^{-3} mm^2/s. [E] FA color map with FA value = 0.44. [F] On CE-MRI the lesion shows heterogeneous enhancement. [G] Time SI curve with washout on delayed phase, TTP was 40 seconds.

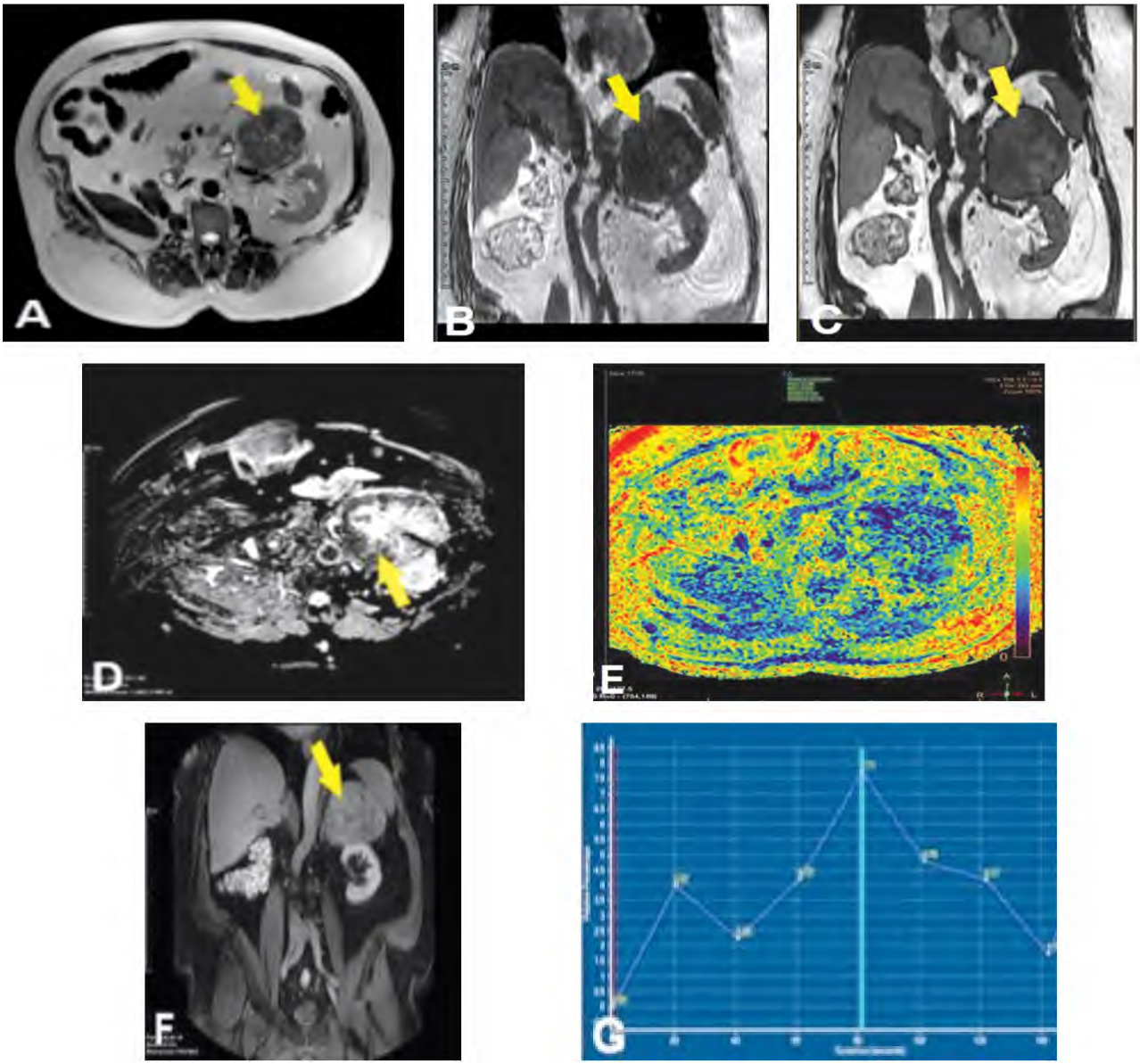

Fig. (5): Case of metastasis from renal cell carcinoma in a 57-years old patient. [A] Axial T2-WI revealed left adrenal lesion showing isoto low SI with areas of cystic necrosis. [B, C] IP and OP images revealed no significant signal drop of the lesion in OP with ASII = 16 %. [D] ADC map: The solid peripheral part of the lesion showed low SI on ADC map. The mean ADC value =1.3 x 10^{-3} mm^2/s. [E] FA color map with FA value=0.28. [F] On CE-MRI the lesion shows heterogeneous enhancement. [G] Time SI curve, TTP was 80 seconds.

Discussion

Adrenal nodules are common incidental findings in radiology daily routine with lipid-rich adenomas are the most frequently encountered lesions. Most adenomas are well characterized on non-contrast CT and no additional studies are required. However, lipid-poor adenomasmay not be fully characterized on CT or even CSI. These indeterminate lesions pose management dilemmas. It should be considered that some non-adenomas may contain high lipid, such as lipid-rich adrenal metastases from extra-adrenal primary tumors that cause apotential analysis pitfall ***[4,29-31]***.

In cases of indeterminate lesions on CSI, evaluation of enhancement pattern can help in differentiation between benign and malignant lesions. Previous research has suggested delayed CE-MRI may be useful in characterizing adrenal tumors, since SI loss is usually greater in adenomas than in non-adenomas, with characteristic early enhancement and rapid washout. The enhancement pattern of an arterial blush is highly suggestive of adenoma, even with negligible SI loss on OP images. Absence of capillary blush is noted in malignant lesions ***[32, 33]***.

In this study, multi parametric MRI was done to review and characterize the imaging features of

different adrenal lesions. Forty patients with 42 adrenal lesions were included in this study. Adenomatous group included 14 lesions, and non-adenomatous group included 28 lesions.

We analyzed the size of the adrenal lesions, which revealed that most adenomas (12 cases) were <5cm. In metastases, the size was variable with most lesions (5 masses) were >5cm. All included ACCs were >5cm. which suggests thatsize measurement could be helpful in differentiating adenomas from non-adenomas.

Our results is supported by Mayo-Smith et al., who stated that for lesions larger than 5cm, ACC had better to be strongly suggested, principally in patients with no previous history of malignancy [30]. Also, Tu et al., found that adrenal metastases were larger than adenomas with statistically significant difference (34mm±20) vs. (15mm±4), (p<0.001) [34]. However, in their study, Bokhari et al., found that myelolipomas were variable in size and may reach very large size, but are definitely recognized due to the presence of macroscopic fat [35].

As regard T2-SI, the present study revealed that most adenomas (10 out of 14) had iso- to low SI. In contrast most ACCs (6 out of 8) had high or heterogeneous high SI and most metastatic lesions (7 out of 8) had heterogeneous high SI. Also, most PCCs (4 out of 5) had high SI and single lesion appeared heterogeneously high on T2-WI.

This came in agreement with Albano et al., who stated that on T2-WI, adrenal adenomas were homogeneous and presented intermediate-low SI similar to normal gland. They added that metastases and ACCs generally appeared moderately hyper-intense and heterogeneously hyper-intense on T2-WI. Additionally, they mentioned that MRI is highly sensitive for the diagnosis of PCC as it appears hyper-intense on T2-WI [31]. Becker-Weidman et al., explained the unusualelevated T2-SI and heterogeneous arterial enhancement in some lipid-poor adenomas due to the presence of extensive internal degeneration on histopathologic analysis in these cases [25]. Also, in their study, Yamauchi et al., analyzed the T2-SI characteristics of adrenal lesionsand revealed a statistically significant difference among groups, showing a tendency of non-adenomas to be more heterogeneous with high T2-SI, while adenomas tends to have homogenous low T2-SI. (p<0.001) [32].

CSI has been used in differentiating adenomas from malignant adrenal masses due to its ability to detect intra-tumoral fat [18]. As regard CSI, the results of qualitative analysis of the signal loss on OP images were as follows: Most adenomas showed significant signal loss. On the other hand,only one metastatic lesion showed signal loss. Also, none of the ACC or PCC lesions showed signal loss. There was a statically significant difference (p-value =0.01). This came in agreement with a study done by Rodacki et al., they found that significant SI drop was detected in 150 adenomas and 2 metastases while negligible SI drop was found in 8 adenomas and 46 metastases. All included ACC and PCC lesions showed negligible SI loss. They concluded that presence of significant SI drop indicated that a lesion was an adenoma. In their study, the AUC was 0.952 with 87% sensitivity and 95% specificity [18].

As regard quantitative analysis by calculation of ASII, our study revealed that ASII was significantly higher in adenomas than non-adenomas (p-value = 0.01). The mean adenomas ASII value was 63%. While in ACCs, metastases and PCCs the mean ASII was 23%, 19% and 21% respectively. At cut off value of 23% the sensitivity was 92% and the specificity was 78% for differentiation between adenomas and non-adenomas.

Our results came in agreement with Afifi et al., who reported that quantitative CSI parameters showed significant statistical difference between adenomas and non-adenomas. They added that the mean value of ASII was 54.52% (30.5-71.2) for adenomas and 6.65% (0.4-16.3) for non-adenomas. Moreover, they added that the accuracy for differentiating adrenal adenomas from non-adenomas was 100%, and cut-off value measured from the ROC curve denote that any adrenal lesion with ASII ≥23.4% indicated adenoma [36].

Regarding DWI, our study revealed that the mean ADC value of adenomas (1.4±0.22 x 10^{-3} mm^2/s) was slightly higher than non-adenomas (1.2±0.24 x 10^{-3} mm^2/s), however it did not reach-statistically significant difference.

These findings came in agreement with Ciçekçi et al., whose study showed that no statistically significant difference was detected between ADC values of benign and malignant adrenal lesions, non-adenomatous benign lesions and malignant lesions, adenomas and non-adenomas, adenomas and metastases, adenomas and PCCs, metastases and PCCs. They concluded that ADC values are not helpful in differentiating between solid adrenal masses [37]. Our findings are also in agreement with Isik et al., study who reported that the median ADC value of metastases (1.29 x 10^{-3} mm^2/s) was lower than the median ADC value of adenomas (1.44 x 10^{-3} mm^2/s), but this difference was not statistically significant [38].

The data relating to DWI in adrenal tumors has been disappointing because adrenal adenomas tend to demonstrate restricted diffusion [39]. In their study El-Kalioubie et al., found a significant difference between the mean ADC values of benign and malignant adrenal lesions (1.78 x 10-3mm^2/s versus 0.92 x 10^{-3} mm^2/s respectively, p<0.001). They reported that, despite the statistically significant

difference in the mean ADC values of benign and malignant lesions, there was overall a considerable overlap between the two groups, rendering ADC values of lower importance in lesion characterization. They attributed these findings to the fact that adenomas may contain variable amounts of intra-tumoral fat, therefore displaying different degrees of diffusion restriction [40].

DTI can evaluate the anisotropic features of tissues and analyze diffusion in at least 6 different directions. This provides more detailed information regarding the diffusion of water in different tissues. In contrast to ADC data obtained from DWI, FA measures the directional diffusivity of water and has a value between 0 and 1. Therefore, FA may be more sensitive to early ultra-structural tissue changes that occur before obvious changes in the ADC occur [38].

In our study, DTI was done for 12 patients and revealed that mean FA value of adenomas (0.46) was significantly higher than non-adenomas (0.33) with *p*-value=0.01. At cut off value of 0.34 for differentiating adenomas from non-adenomas the sensitivity was 100% and the specificity was 84%. These findings are in agreement with Isik et al., study who reported that the mean FA value ofadrenal adenomas was significantly higher than that of metastases. The median FA value of adenomas was 0.52, whereas for adrenal metastases was 0.35. On ROC analysis, the AUC was 0.936 with a 95% CI. At a cutoff value of 0.40, sensitivity and specificity were 74% and 88% respectively [38].

Regarding visual evaluation of the contrast enhancement patterns on CE-MRI, most adenomas (8 out of 14) showed homogenous enhancement, the other 6 adenomas showed either punctuate, heterogeneous or negligible enhancement. In contrast, 5 out of 8 ACCs displayed heterogeneous enhancement, the remaining 3 ACCs showed homogenous, peripheral or punctuate enhancement. Additionally, 4 out of 8 metastatic lesions showed peripheral enhancement pattern. The remaining 4 metastatic lesions displayed homogenous, heterogeneous or negligible enhancement. There was statistically significant difference with *p*-value=0.02.

This coincided with Inan et al., study who stated that 36 of the included 48 adenomas showed homogeneous enhancement, 10 adenomas showed punctuate enhancement, single lesion showed peripheral enhancement and single lesion showed negligible enhancement. While malignant masses showed heterogeneous enhancement (9 out of 16 lesions) or peripheral enhancement (4 out of 16), 2 lesions showed punctuate enhancement and single lesion showed homogenous enhancement [41]. Also, in their study (205 patients with 239 adrenal lesions), Rodacki et al., found that most adenomas showed either an arterial blush or homogeneous enhancement even in lesions with negligible SI loss on CSI (lipid-poor adenomas), whereas most metastases exhibited early peripheral or heterogeneous enhancement [18].

Regarding quantitative assessment of DCE-MRI using TTP enhancement, adenomas had significantly lower TTP (range 40-69 seconds) than non-adenomas (range 55-167 seconds) with *p*-value = 0.01. In ROC curve analysis of TTP in differentiation of adenomas from non-adenomas, the AUC was 0.929. By using cut off value for TTP of 43 seconds, the sensitivity was 100% and the specificity was 60%.

In malignant lesions, there is expansion of the extracellular space secondary to tumoral infiltration and loss of cell membrane integrity, this leads to contrast material retention in the extravascular space fora longer duration. This results in slower enhancement and prolonged contrast material retention within the tumor with no capillary blush on immediate contrast-enhanced images. Peripheral and patchy enhancement with slow and progressive enhancing patternis recognized in most non-adenomas [18].

In their study, Rodacki et al., analyzed SI-time curve and found that adenomas had the greatest early enhancement persisting through the first 60 seconds, whereas metastases and PCCs reached maximal enhancement in the interstitial phase (slow progressive) [18]. Also similarfindings are shown in the study by Inan et al., that included 64 masses (48 adenomas, 16 malignant tumors), they reported that TTP enhancement of malignant tumors was significantly longer than that of adenomas. With a cut-off value of 52.85s, TTP enhancement had sensitivity and specificity of 87.5% and 80% respectively in differentiating adenomas from malignant lesions [41]. This also copes with Korivi & Elsayes study who stated that in DCE-MRI, TTP enhancement was the best indicator to differentiate adenomas from malignant lesions. Typically, TTP enhancement was 40 seconds for adenomaswhile for malignant lesions was 65 seconds. At cut of value of 53 seconds, the sensitivity was 87.5% and the specificity was 80% for adenoma differentiation from malignant conditions [42].

The limitations of our study were as follows: Pathologic confirmation was not available for 7 benign lesions depending on their stable radiologic appearance on regular follow-up. Alsosmall sample size ofpatients underwent DTI as this was not planned primarily in the design of the study. Further studies with larger sample size is needed to validate our results.

Conclusions:

The additive results of multiparametric MRI including conventional imaging, CSI, DWI, DTI as well as DCE-MRI can help in solving the dilemma

of differentiating adrenal adenomas from non-adenomatous lesions. It also provide clues toincrease the diagnostic confidence and avoid potential misinterpretation of these entities.

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الأداء التشخيصى لتقنيات الرنين المغناطيسى المتعدده للتفرقه بين آفات الغده الكظرى

إن امراض الغده الكظرية العرضية التي تم اكتشافها فى التصويرالمقطعى بالصدفه هى سيناريو سريرى شائع، حيث انها توجد فى ما يقرب من ٥٪ من جميع فحوصات البطن. وتعتبر التفرقه بين الامراض الحميده والخبيثه أمرًا مهماً للتنبؤ بالمرض الأولى، وتقييم التشخيص والعلاج، واستبعاد الحاجة إلى كل من العينات أو الجراحه فى هؤلاء المرضى.

الغرض من هذه الدراسة: هو تقييم أداء التصوير بالرنين المغناطيسى متعدد التقنيات بما فى ذلك التصوير التقليدى والتحول الكيميائى والتصوير بالرنين المغناطيسى الانتشارى والتصوير الديناميكى بالصبغه للتمييز بين أورام الغدة الكظرية الحميده والخبيثة .

تم عمل هذه الدراسه فى الفتره ما بين أبريل ٢٠١٨ ويوليو ٢٠٢٢، تم فحص ٤٠ مريضاً يعانون من ٤٢ آفه فى الغده الكظرية وتم تأكيد التشخيص النهائى عن طريق العينات وتحليل الأنسجه أو المتابعه الدوريه بالرنين المغناطيسى.

نتائج البحث : اظهرت ان الاورام الحميد تظهر اشاره منخفضه فى التصوير المغناطيسى العادى، بينما فى التصوير بالتحول الكيميائى تنخفض الاشاره وبحساب المعادله تم الوصول لرقم ٢٣٪ للفصل بينها وبين الاورام الخبيثه.

وقد تبين ايضاً ان التصويرالمغناطيسى الانتشارى لم يستطع التفرقه بينهم، بينما استطاع التصوير الموترالانتشار فى التفريق بينهم. اما التصوير الديناميكى بالصبغه استطاع التفرقه بينهم حيث اظهرت النتائج ان زمن الوصول للاشاره القصوى للصبغه يكون اقصر فى الاورام الحميده عن الاورام الخبيثه.

الإستنتاج: إن التصوير بالرنين المغناطيسى متعدد التقنيات بما فى ذلك التصوير التقليدى والإنتشارى وموتر الإنتشار والتحول الكيميائى والديناميكى بالصبغه يمنح دقة أكبر فى التمييزبين أورام الغدة الكظريه الحميده والخبيثه وهو أمر بالغ الأهمية.