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KIDNEYS, URETERS, BLADDER, RETROPERITONEUM

Characterization of adrenal lesions on chemical shift MRI: comparison of 1.5 T and 3 T MRI

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Abstract

Purpose To compare three chemical shift MRI techniques [two-dimensional (2D) dual gradient echo (dGRE), 3D VIBE, and 3D VIBE-Dixon] at 3 T and 2D dGRE technique at 1.5 T to assess their ability of detecting microscopic fat in adrenal adenomas and differentiating between adenomas and non-adenomas.

Methods Seventy-eight patients with 97 lesions (78 adenomas, 19 non-adenomas) underwent both 1.5 T and 3 T chemical shift MRI. The Wilcoxon signed-ranked test was used to determine if there was significant difference between the signal intensity index (SII) values of each technique to assess their ability to detect microscopic fat in adrenal adenomas. ROC analysis was performed for the SII values of each technique, the adrenal-to-spleen SI ratio of 2D dGRE technique at 3 T, and the fat fraction values of the 3D VIBE-Dixon technique to identify the optimal threshold for differentiation of adrenal adenomas from non-adenomas.

Results For detection of microscopic fat, the mean SII value of 2D dGRE technique at 1.5 T was significantly higher than that of the chemical shift imaging techniques at 3 T ($p = 0.001$). For discrimination of adenomas from non-adenomas, the area under the curve (AUC) and 95% confidence interval values of 2D dGRE technique at 1.5 T and 2D dGRE, 3D VIBE, 3D VIBE-Dixon techniques at 3 T were calculated as 1.00 (1.00–1.00), 0.991 (0.978–1.00), 0.999 (0.995–1.00), 0.993 (0.979–1.00), respectively, for the SII.

Conclusion Chemical shift MRI at 1.5 T using the 2D dGRE technique provided the most accurate differentiation between adenomas and non-adenomas. However, there was no statistically significant difference between chemical shift imaging techniques at 1.5 T and 3 T.

Keywords Adrenal adenoma · Adrenal glands · Chemical shift imaging · MRI

Introduction

The widespread use of imaging has led to increased detection of adrenal lesions and has underlined the importance of accurate adrenal lesion characterization [1, 2]. Incidental adrenal nodules in patients with no known primary malignancy are present on approximately 5% of all abdominal CT examinations [3, 4]. The incidence of an adrenal nodule further increases to 9-13% in patients being scanned for a known primary malignancy, but only 26–36% of them are metastatic [5]. Therefore, accurate differentiation of benign adenomas and non-adenomas is crucial in patients with a known primary malignancy.

Chemical shift magnetic resonance (MR) imaging with in-phase (IP) and opposed-phase (OP) acquisition is the most sensitive radiologic technique attempting to differentiate adrenal adenomas from metastases [6]. Signal intensity (SI) alterations between the IP and OP images, owing to inherent differences in the resonant frequencies of fat and water protons, accurately demonstrate the presence of intracytoplasmic fat, a finding that is typically consistent with adrenal adenomas, contrary to adrenal metastases [7].

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The vast majority of published literature has appraised chemical shift imaging of adrenal lesions using 1.5 T MR systems. Nevertheless, significant differences between 1.5 T and 3 T chemical shift imaging exist [8]. The difference in magnetic field strength causes a different precession frequency for fat and water protons and alters the tissue-specific differences in T1 relaxation time between 1.5 T and 3 T MR systems [8–11]. At 1.5 T, the phase shift from IP to OP occurs every 2.2 ms, and at 3 T, it occurs every 1.1 ms [10, 11]. This difference leads to selection of different TE pairs in 3 T MR systems which alter the contribution of T2* effects to the differences in SI between IP and OP [8]. Furthermore, the acquisition of the first OP echo at 1.1 ms and the first IP echo at 2.2 ms within the same breath-hold would bring about some technical difficulties in 3 T MRI units [8, 11]. All these differences between 1.5 T and 3 T MRI systems restrain application of established quantitative signal loss thresholds derived from studies performed at 1.5 T to clinical imaging performed at 3 T and changes the diagnostic efficacy of 3 T MRI systems [8].

The use of chemical shift imaging for characterization of adrenal lesions at 1.5 T is well established, but there is a paucity of data at 3 T. Furthermore, there is no consensus in the literature about the optimal sequence parameters for chemical shift MRI at 3 T. The number of studies in the literature which have evaluated the effectiveness of chemical shift imaging for characterization of adrenal lesions at 3 T is limited [7, 8, 11–15]. Only two of them have compared 1.5 T and 3 T chemical shift imaging [8, 14], and to the best of our knowledge, only a single study has reported a direct intra-individual comparison of chemical shift imaging in discriminating adenomas and non-adenomas at 1.5 T and 3 T [8]. However, none of these studies were prospectively designed. Thus, the purpose of our study was to prospectively compare all possible chemical shift imaging techniques of our 3 T MR unit [two-dimensional (2D) dual gradient echo (dGRE), 3D VIBE, and 3D VIBE-Dixon] to 2D dGRE chemical shift imaging at 1.5 T to assess their abilities to detect microscopic fat in adrenal adenoma and their usefulness for differentiating adrenal adenomas from non-adenomas.

Materials and methods

Study approval and patient population

Our institutional review board approved this single-center, prospective, clinical study, and written informed consent was obtained from all patients included in the study. Between November 2015 and February 2017, 84 patients with 115 adrenal masses were studied prospectively with chemical shift MRI at both 1.5 T and 3 T in the same session. Among these lesions, adrenal cysts ($n=1$) and lesions containing macroscopic fat (indicative of myelolipoma, $n=1$) were excluded due to the fact that chemical shift MRI is not used for characterization of these lesions. Lesions measuring a maximum of 1 cm or less in the transverse or coronal diameter were excluded because of difficulty in accurately placing a region of interest (ROI, $n=4$). Eight lesions diagnosed as adrenal hyperplasia in patients with no known primary malignancy and one lesion which had hemorrhagic content were also excluded. Three others were excluded owing to poor image quality due to motion artifact. The remaining 77 patients (mean age, 59 years; age range 32–77 years) with 97 adrenal lesions comprised our study cohort, which included 52 (67.5%) women and 25 (32.5%) men. A flowchart of the study is depicted in Fig. 1.

Reference standard

A lesion was diagnosed as a benign adrenal adenoma on the basis of imaging stability (less than 10% variation in size) during MR imaging follow-up over a minimum 12 months ($n=67$), unenhanced CT attenuation values of less than 10 HU, or both ($n=11$). A lesion was classified as a non-adenoma on the basis of histologic confirmation at surgery ($n=2$) or occurrence of new adrenal lesion on follow-up images in patients with a known primary malignancy ($n=17$).

In 66 of the 77 patients, 78 adrenal lesions were diagnosed as adenomas (mean maximal diameter, 2.3 cm; range 1.0–4.5 cm); this included 54 (81.8%) patients with unilateral and 12 (18.2%) patients with bilateral lesions. In two patients, 2 (2.6%) of the 78 adenomas were diagnosed as lipid-poor adenomas on unenhanced CT based on lesion attenuation greater than 10 HU (with attenuation values of 26 HU and 18 HU). These two lesions were confirmed by follow-up (less than 10% variation in size). Of 11 patients with 19 adrenal lesions diagnosed as non-adenomas (mean maximal diameter, 3.3 cm; range 1.3–9.6 cm), 6 (54.5%) patients had unilateral and 5 (45.5%) patients had bilateral lesions. Among those with non-adenomas, 18 adrenal lesions that did not exist on the baseline imaging and were newly identified during follow-up of 10 patients with a known primary malignancy were diagnosed as metastases. This group included three metastases from breast cancer in two patients, five metastases from clear-cell renal cell carcinoma in two patients, five metastases from lung cancer in four patients (one of which was pathologically proven after surgery), one metastasis from hepatocellular carcinoma in one patient, three metastases from nasopharyngeal carcinoma in one patient (Fig. 2). The remaining non-adenoma was a primary neoplasm of the adrenal gland which was diagnosed as pheochromocytoma after surgical resection.

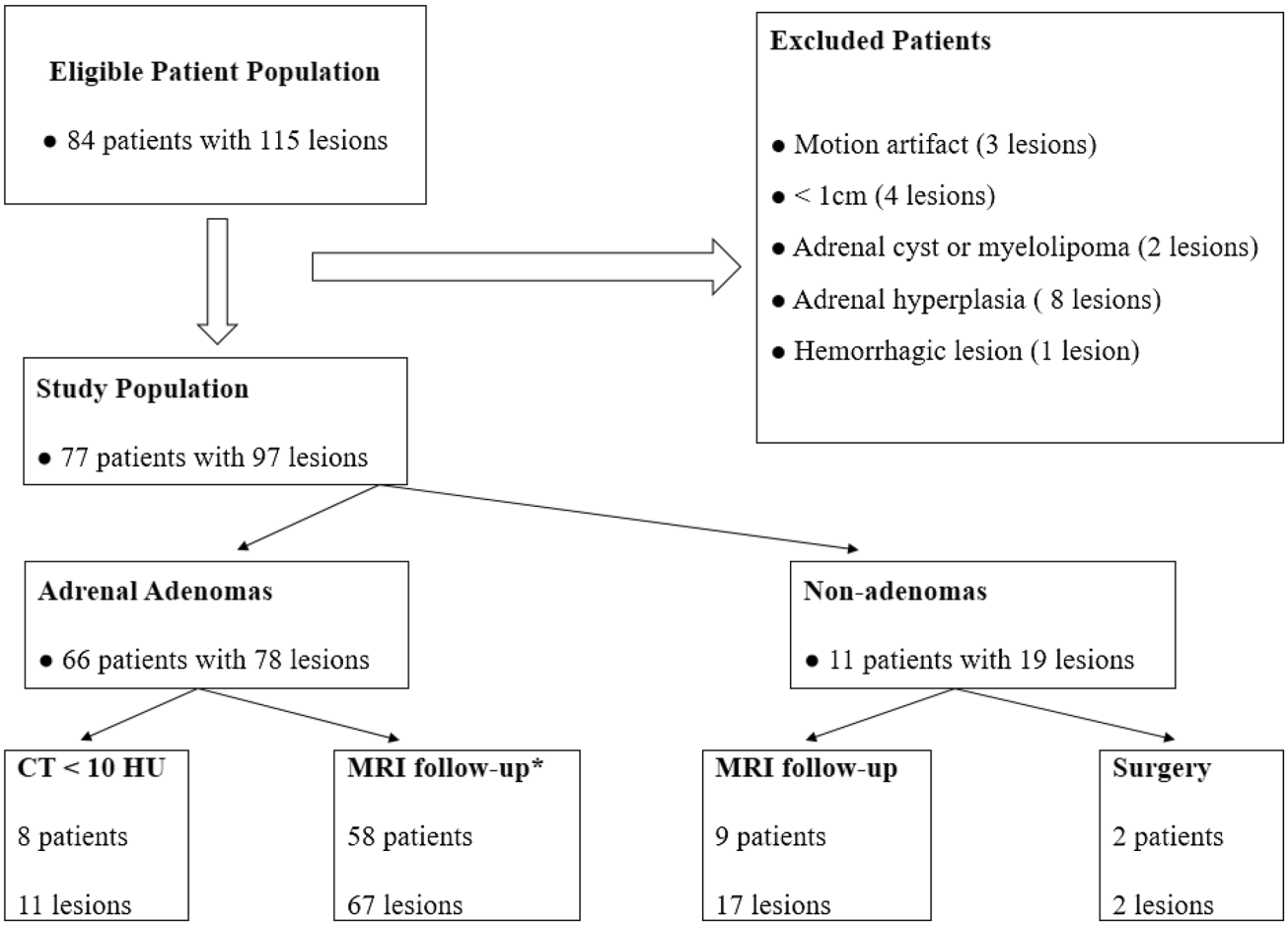

Fig. 1 Flowchart of study enrollment population. (*) MRI follow-up was for a minimum of 12 months—an adenoma was diagnosed if the lesion had < 10% increase in size

MR technique

All patients underwent both 1.5 T and 3 T MR imaging. MR imaging was performed on a 1.5 T unit (Magnetom Symphony, Siemens Medical Solutions, Germany) with a phase-array body coil. Our standard adrenal imaging protocol included a half-Fourier single-shot turbo spin echo (HASTE) T2-weighted sequence in the coronal and transverse planes, axial fat-suppressed T1 W images, and a single breath-hold 2D dual GRE sequence. The 2D technique comprised the first opposed-phase (OP) and first in-phase (IP) echo (TE of 2.32 and 5.24 ms, respectively) with a repetition time of 100 ms (Table 1).

For 3 T, we used a 3 T unit (Magnetom Verio, Siemens Medical Solutions, Germany) and a phase-array body coil. The IP and OP sequences were acquired in a single breath-hold using 2D dGRE, 3D VIBE, and 3D VIBE-Dixon sequences. With 2D technique, the first IP echo and third OP echo were acquired at an echo time of 2.46 and 6.15 ms, respectively, with a repetition time of 130 ms. These TE values were recommended by all three major MR vendors (GE Healthcare, Philips Medical Systems, and Siemens Medical Solutions) at 3 T due to the challenge of obtaining consecutive in- and opposed-phase TEs owing to their closer temporal spacing compared with that at 1.5 T [11]. The 3D VIBE technique comprised the first OP echo and first IP echo (echo time, 1.33 and 2.45 ms) with a repetition time of 4.36 ms. Using the 3D VIBE-Dixon technique, the first IP and second OP echo were acquired at echo times of 2.45 and 3.675 ms, respectively, with a repetition time of 5.47 ms (Table 1). This combination reflects the only possible TE pair that can be acquired using the 3D VIBE-Dixon technique on our 3 T unit. All sequences were within the regulated radiofrequency and gradient limits, and earplugs or headphones were used by all patients.

Image analysis

For quantitative measurements, an image analysis workstation (Leonardo, Siemens Medical Solutions) was used. Analysis was performed by the same radiologist (5 years of

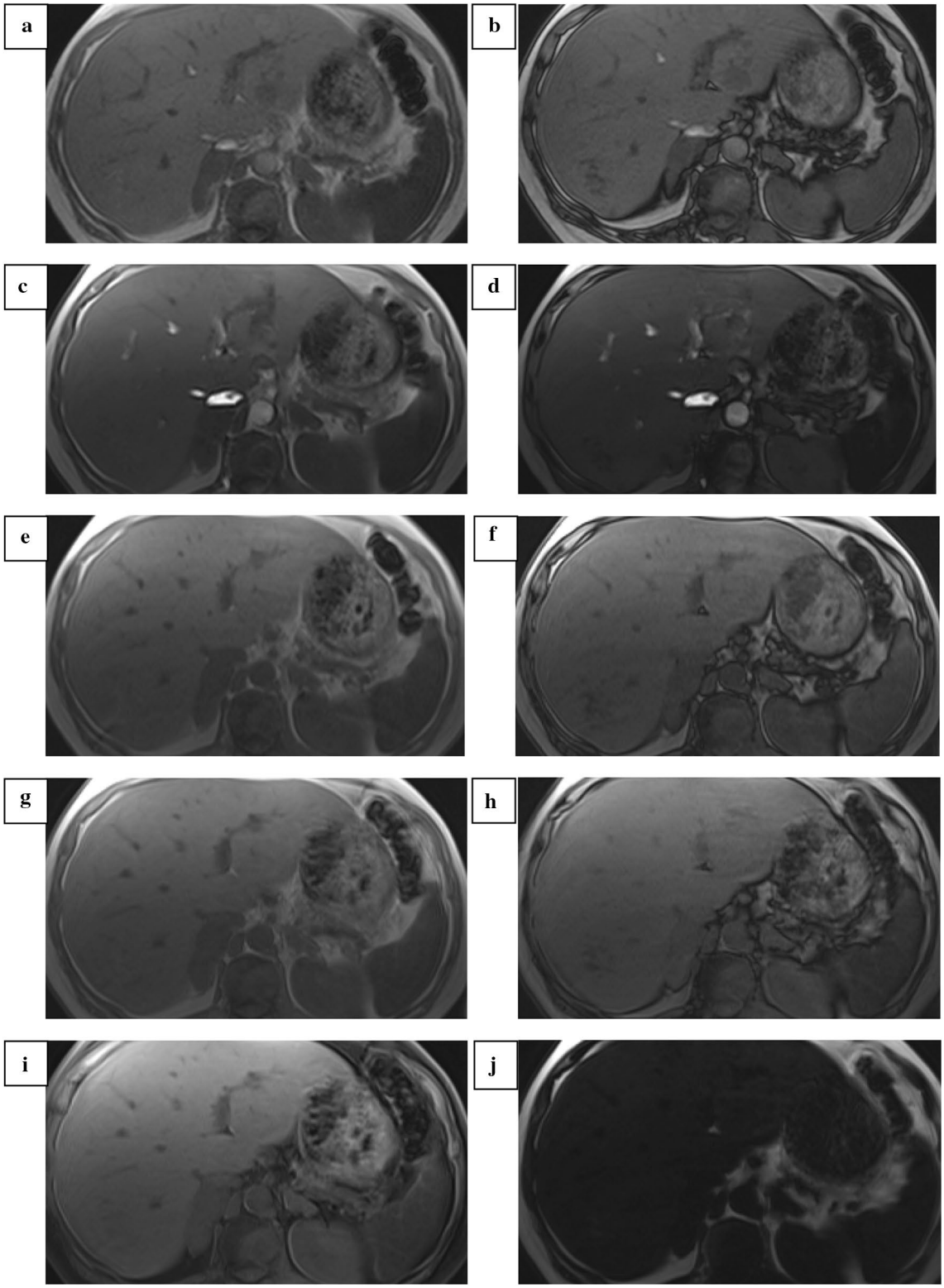

Fig. 2 New lesions in both adrenal glands of a 76-year-old man with known nasopharyngeal carcinoma. There is no significant signal loss on the OP images (**b**, **d**, **f**, **h**) with all four chemical shift imaging techniques [1.5 T 2D dGRE (**a**, **b**), 3 T 2D dGRE (**c**, **d**), 3 T 3D VIBE (**e**, **f**), 3 T VIBE-Dixon (**g**, **h**)]. The fat fraction values were calculated from water-only/fat-only images (**i**, **j**), which were consistent with a diagnosis of non-adenoma. Lesions were accepted as metastases due to their new occurrence on follow-up images

Table 1 MR imaging sequences and parameters

Sequence	1.5 T	3 T		
	2D dGRE	2D dGRE	3D dGRE	3D VIBE-Dixon
Plane	Transverse	Transverse	Transverse	Transverse
Repetition time (ms)	100	130	4.36	5.47
Echo time OP/IP (ms)	2.32/5.24	6.15/2.46	1.33/2.45	2.45/3.675
Flip angle	70	70	9	9
Bandwith (Hz/pixel)	380	280	980/680	500/780
Matrix	173/256	203/320	169/320	168/320
Field of view (mm)	400	380	380	380
Section thickness (mm)	5.5	5	3	3
Intersection gap	2.1	1	–	–
Parallel imaging type	–	GRAPPA	GRAPPA	GRAPPA
Respiratory control	Breath-hold	Breath-hold	Breath-hold	Breath-hold

dGRE Dual gradient echo, *OP/IP* opposed-phase/in-phase, *VIBE* volumetric interpolated breath hold examination

experience in abdominal MRI) in random order, with 1.5 T and 3 T examinations intermixed. For each patient, OP, IP, water-only, and fat-only images were displayed side-by-side at the level of the target adrenal lesion. SI measurements of the adrenal lesions were obtained by manually placing circular or oval ROI at the same locations in sections at the same image level for both OP/IP datasets and fat/water datasets by means of the copy-and-paste function of workstation. The freehand ROI was placed in the adrenal lesion on the OP image and was drawn as large as possible to encompass as much of the adrenal lesion as possible while excluding the edges of the lesion. ROIs were approximately one-half to two-thirds the size of each lesion and were placed in artifact-free, homogenous areas of the lesions. SI measurement was performed twice for each lesion at two consecutive levels (the maximum transverse diameter of the lesion and the adjacent imaging slice if possible); if the lesion was detected on only a single image level, then the radiologist deleted the original ROI and placed a second ROI on the same image level. Average values were calculated. All measurements were blinded to clinical data.

Additional reference ROIs were drawn in each case within the spleen on 2D dGRE images from the 3 T MR unit. SI measurements of the spleen were obtained on the same slice as the adrenal lesion ROI while avoiding organ edges, vessels, or artifact, and each SI value was measured twice. For patients, in whom splenic tissue was not present at level of the adrenal lesion, the SI measurements of the spleen were obtained on the first available image. On the basis of mean SI values of the adrenal lesions and the spleen on the OP/IP images and mean SI values of the adrenal lesions on the fat/water datasets, the SII, fat fraction, and adrenal-to-spleen SI ratio were calculated according to the previously validated equations [16] as follows:

$$\mathrm{SII} = \left[\mathrm{SI\,(adrenal)}_{\mathrm{in-phase}} - \mathrm{SI\,(adrenal)}_{\mathrm{opposed-phase}} \Big/ \mathrm{SI\,(adrenal)}_{\mathrm{in-phase}}\right] \times 100\%$$

$$\text{Fat fraction} = \left[\mathrm{SI\,(adrenal)}_{\mathrm{fat-only}} \Big/ \mathrm{SI\,(adrenal)}_{\mathrm{fat-only}} + \mathrm{SI\,(adrenal)}_{\mathrm{water-only}}\right] \times 100\%.$$

$$\text{Adrenal-to-spleen SI ratio} = \left[\left(\mathrm{SI(adrenal)}_{\text{opposed-phase}} \Big/ \mathrm{SI(spleen)}_{\text{opposed-phase}}\right) \Big/ \left(\mathrm{SI(adrenal)}_{\text{in-phase}} \Big/ \mathrm{SI(spleen)}_{\text{in-phase}}\right) - 1\right] \times 100\%$$

Statistical analysis

The Wilcoxon signed-ranked test was used to determine if there was a statistically significant difference between the SII values of the each sequence to assess their ability of detecting microscopic fat in adrenal adenomas. ROC analysis was performed, and the area under the curve (AUC) was determined for the SII values of each technique, the fat fraction values of the 3D VIBE-Dixon technique, and the adrenal-to-spleen SI ratios of the 2D dGRE technique of the 3 T MR unit to identify the optimal threshold that maximized the sum of the sensitivity and the specificity for differentiating adrenal adenomas from non-adenomas. A p value of less than 0.05 was regarded as statistically significant. Statistical analysis was performed using Statistical Package for the Social Sciences version 18.0 (SPSS Inc., Chicago, IL, USA) for Windows (Microsoft).

Results

For detecting microscopic fat in adrenal adenomas, on the basis of quantitative assessment of signal loss between in- and opposed-phase images (Table 2), the mean SII values of the 2D dGRE technique at 1.5 T were significantly higher than all of the chemical shift imaging techniques at 3 T ($p = 0.001$). Among 3 T sequences, the mean SII value of the 3D VIBE technique was significantly higher than the other sequences at 3 T ($p = 0.001$). However, there was no statistically significant difference between the mean SII values of the 2D dGRE and 3D VIBE-Dixon techniques at 3 T ($p = 0.685$).

For all sequences, the mean SII value for the 3D VIBE-Dixon sequence, the mean fat fraction value, and for the 2D dGRE sequence at 3 T, the mean adrenal-to-spleen SI ratios were significantly different between adenomas and non-adenomas ($p = 0.001$, Table 2). When an SII of 11.2% was chosen as the threshold, there was no overlap in the SII between adenomas and non-adenomas on 2D dGRE images at 1.5 T. However, the box-and-whisker plots for the SII at 3 T showed an overlap of four lesions (two lipid-poor adenomas and two renal cell carcinoma metastases) when using the 2D dGRE technique, two lesions (one lipid-poor adenoma and one renal cell carcinoma metastasis) when using the 3D VIBE technique, two lesions (one lipid-poor adenoma and one renal cell carcinoma metastasis) when using the 3D VIBE-Dixon technique. Furthermore, there was an overlap of one lipid-poor adenoma when using the fat fraction method of the 3D VIBE-Dixon technique and two lesions (two lipid-poor adenomas) when using the adrenal-to-spleen SI ratio of the 2D dGRE technique at 3 T (Fig. 3). One lipid-poor adenoma was correctly diagnosed only on the 2D dGRE 1.5 T MR images (Fig. 4).

Mean AUC values among the various evaluation methods did not significantly differ from one another (Table 3). Among all sequences, the sensitivity and specificity were higher when using the 2D dGRE technique at 1.5 T, and among 3 T sequences, they were higher when using the 3D techniques. Nevertheless, none of the differences were statistically significant. With the 2D technique at 1.5 T, sensitivity and specificity were 100% for the SII with a suggested threshold value of 11.2%. With the 2D technique at 3 T, sensitivity and specificity were 97.4% and 89.5%, respectively, for the SII with a suggested threshold value of 38.4%. We also evaluated the adrenal-to-spleen SI ratio for 2D dGRE technique at 3 T, and its sensitivity/specificity were 97.4% and 100%, respectively, with a suggested threshold value of -20.5%. Sensitivity and specificity for the SII of the 3D VIBE and 3D VIBE-Dixon techniques at 3 T were 98.7% and 94.7%, respectively, with suggested threshold values of 12.3% and 17.1%, respectively. The sensitivity and specificity for the 3D VIBE-Dixon technique at the suggested threshold of fat fraction (12.9%) were 98.7% and 100%, respectively.

Table 2 The mean SII values (± standard deviation of mean) of adrenal adenomas/non-adenomas at 1.5 T and 3 T sequences, and the mean fat fraction values for the 3D VIBE-dixon technique at 3 T

Sequence	Adenoma	Non-adenoma
1.5 T 2D dGRE	72.32 ± 13.66	4.41 ± 3.58
3 T 2D dGRE	58.44 ± 11.25	17.96 ± 10.24
3 T 2D dGRE (Adrenal-to-Spleen SI Ratio)	− 52.27 ± 1.63	16.47 ± 7.31
3 T 3D VIBE	69.11 ± 11.39	− 0.86 ± 9.44
3 T 3D VIBE-Dixon (SII)	57.76 ± 13.17	3.78 ± 7.21
3 T 3D VIBE-Dixon (Fat Fraction)	30.10 ± 5.83	8.63 ± 2.04

dGRE Dual gradient echo, *SI* signal intensity, *SII* signal intensity index, *VIBE* volumetric interpolated breath hold examination

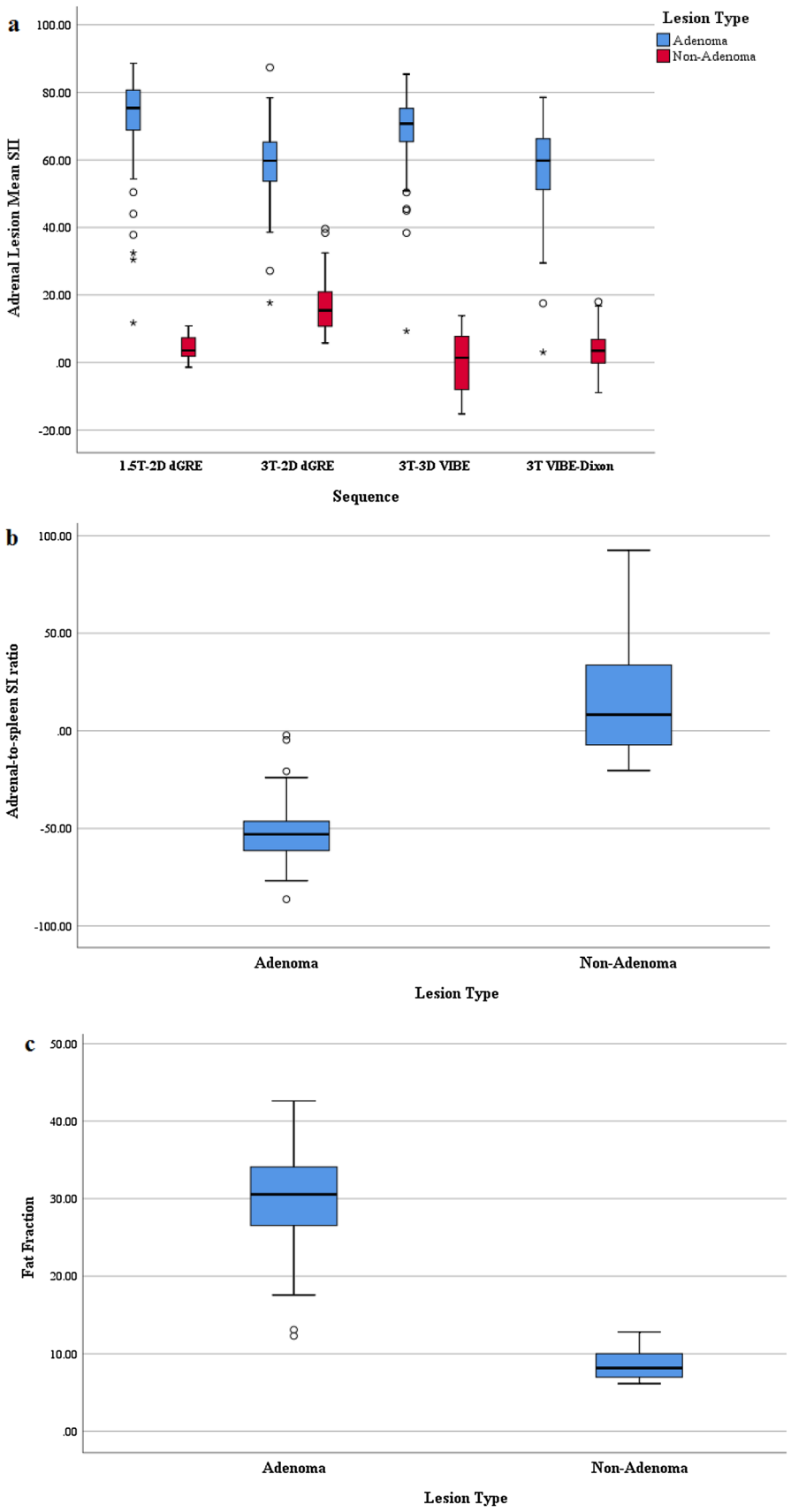

Fig. 3 Box-and-whisker plots for **a** the signal intensity index (SII) of all four sequences, **b** the adrenal-to-spleen SI ratio of the 2D dGRE technique at 3 T, and **c** the fat fraction of the 3D VIBE-Dixon technique at 3 T. There was a statistically significant difference between adenomas and non-adenomas regarding each quantitative method. For the SII, overlaps occurred in four lesions with the 2D dGRE technique at 3 T and two lesions with the 3D VIBE and VIBE-Dixon technique at 3 T. For the adrenal-to-spleen SI ratio and fat fraction, overlap occurred in two lipid-poor adenomas and one lipid-poor adenoma, when using the 2D dGRE and 3D VIBE-Dixon techniques, respectively

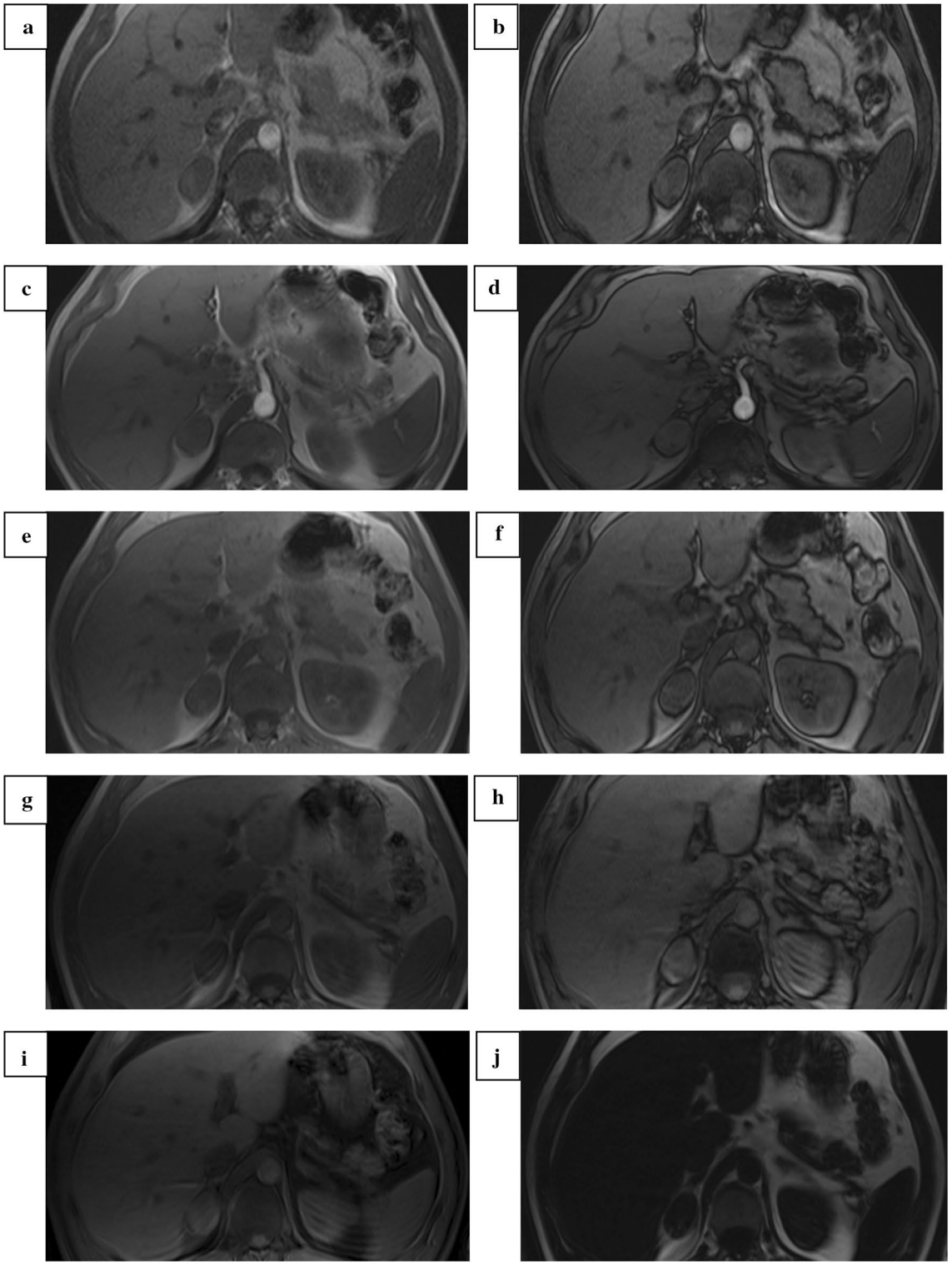

Fig. 4 A 56-year-old woman with an incidentally discovered lipid-poor right adrenal adenoma, which was confirmed with unenhanced and contrast-enhanced CT (with an attenuation value of 26 HU on unenhanced CT and 61% absolute wash-out on contrast-enhanced CT). Afterward, the patient was followed up with MRI. The IP (**a**) and OP (**b**) images of the 2D dGRE technique at 1.5 T are the only sequence that depict the signal loss within the adenoma (signal intensity index of 11.3%). There is no significant signal loss on the remaining chemical shift imaging techniques [3 T 2D dGRE (**c**, **d**), 3 T 3D VIBE (**e**, **f**), 3 T VIBE-Dixon (**g**, **h**)]. The fat fraction was calculated from water-only/fat-only images (**i**, **j**) as 8.9% which was consistent with a non-adenoma

Table 3 Sensitivity, specificity, accuracy, suggested threshold, and AUC values of the sequences at 1.5 T and 3 T

Sequence	Sensitivity	Specificity	Accuracy	Suggested threshold (%)	AUC
1.5 T 2D dGRE	100	100	100	11.2*	1.00 (1.00–1.00)
3 T 2D dGRE	97.4	89.5	95.9	38.4*	0.991 (0.978–1.00)
3 T 2D dGRE (Adrenal-to-Spleen SI Ratio)	97.4	100	98	− 20.5**	0.991 (0.978–1.00)
3 T 3D VIBE	98.7	94.7	98	12.3*	0.999 (0.995–1.00)
3 T 3D VIBE-Dixon (SII)	98.7	94.7	98	17.1*	0.993 (0.979–1.00)
3 T 3D VIBE-Dixon (Fat fraction)	98.7	100	99	12.9***	0.999 (0.995–1.00)

The figures in parentheses represent the 95% confidence intervals

AUC area under the receiver operating characteristic curve, *dGRE* dual gradient echo, *VIBE* volumetric interpolated breath hold examination

*SII value, **Adrenal-to-spleen SI ratio, ***Fat fraction value

Discussion

Our study shows a significant difference between 1.5 T and 3 T chemical shift imaging for the detection of microscopic fat in adrenal adenomas. In contrast to the study of Ream et al. [8] who found no significant difference on the visual assessment of perceived signal loss between IP and OP images between 1.5 T and 3 T, we found that the 2D dGRE technique using the 1.5 T MR unit had a significantly higher SII value than the other techniques at 3 T. Our quantitative assessment, by mean SII values, showed that the 2D dGRE sequence at 1.5 T was significantly more effective than the all sequences at 3 T for detecting microscopic fat in adrenal adenomas. In addition, the 3D VIBE technique was more effective than the other 3 T sequences for detecting microscopic fat in adrenal adenomas. However, there was no significant difference between the 2D dGRE and 3D VIBE-Dixon techniques at 3 T. Our findings are in general agreement with those of Marin et al. [7], who compared 2D and 3D dGRE techniques at 3 T and who reported the means SII of adrenal adenomas at these sequences as 12.8 and 55.7, respectively.

Our study also demonstrates that adrenal adenomas can be readily differentiated from non-adenomas at 3 T chemical shift imaging. Our clinical data showed that there were no significant differences in average diagnostic accuracy and AUC values between 1.5 T and 3 T chemical shift imaging techniques. At 3 T, although there were no statistically significant differences between sensitivity, specificity, accuracy, and AUC values of the 2D and 3D chemical shift imaging techniques, these values were higher at 3D sequences. This difference is mostly related to the altered sequence parameters between the 2D and 3D chemical shift imaging techniques. There are significant differences in the imaging properties of 3 T and 1.5 T MR units. In a 3 T MR system, fat and water protons are OP relative to each other at 1.1 ms, 3.3 ms, and so on, and IP relative to each other at 2.2 ms, 4.4 ms, and so on [17]. Acquisition of the first OP echo at 1.1 ms and the first IP echo at 2.2 ms within the same breath-hold would require unacceptably high receiver bandwidths. Thus, all three major MR vendors (GE healthcare, Philips, and Siemens) recommended the collection of either the first OP signal and the second IP signal, or the first IP signal and the third OP signal when using 3 T MR systems [18, 19]. In our 3 T MR unit, we were not able to obtain the first OP signal and the second IP signal with the 2D dGRE technique due to technical problems. Because of this, the 2D technique was more prone to the effects of T2* decay than the 3D technique, and higher numbers of non-adenomas had a misleading SI loss on the OP images (as did two non-adenomas in our study). In addition, on the basis of SII values, two lipid-poor adenomas were misdiagnosed as non-adenomas when using the 2D dGRE technique at 3 T. To overcome this issue, the use of internal reference organs has been recommended if the IP echo is collected before the OP echo [11]. In several studies, authors have suggested the spleen as the most suitable reference tissue, since fat infiltration of the liver may influence the quantitative evaluation [12, 16]. Therefore, we also evaluated the adrenal-to-spleen SI ratio when using the 2D dGRE technique at 3 T. Both the SII and adrenal-to-spleen SI ratio had the same sensitivity for discriminating adenomas from non-adenomas, but the specificity increased to 100% when we used the adrenal-to-spleen SI ratio for distinguishing adrenal adenomas from non-adenomas. Although this increment was not statistically significant, the adrenal-to-spleen SI ratio enabled us to correctly diagnose two additional clear-cell renal cell carcinoma metastases compared to those diagnosed by using only the SII. In contrast to our study, Schindera et al. [12] demonstrated some overlap between the adrenal-to-spleen SI ratio values of adenomas and non-adenomas and emphasized that the SI of the spleen could be altered by abnormal iron deposition. Hence, the radiologist who acquires the IP echo before the OP echo and who uses the spleen or liver as an internal reference should be aware of splenic iron deposition and hepatic steatosis [12].

We acquired the first OP and IP images with the 3D dGRE sequence at 3 T. Therefore, the sensitivity, specificity, accuracy, and AUC values were better when using the 3D technique. In addition, this technique has an inherently greater signal-to-noise ratio (SNR), which enables acquisition of thinner sections with no intersection gap and without decreasing image quality. Moreover, the 3D dGRE sequence improves spatial resolution and reduces the effect of partial volume averaging [7]. Among our patients, a lipid-poor adenoma and a metastatic lesion from clear-cell renal cell carcinoma were diagnosed correctly with the 3D dGRE chemical shift imaging technique at 3 T, whereas the 2D dGRE technique did not show these findings. Our results suggest that 3D dGRE chemical shift imaging may improve diagnostic accuracy for lipid-poor adenomas. Additional studies in greater numbers of patients with lipid-poor adenomas are needed to confirm our results.

We also evaluated the efficacy of the 3D VIBE-Dixon sequence using the 3 T MR unit for discrimination of adenomas from non-adenomas. We found no significant difference in diagnostic accuracy between the fat-only datasets, which were reconstructed from 3D dGRE sequence using a two-point Dixon technique, and the OP/IP datasets for distinguishing adenomas from non-adenomas according to their fat fraction and SII values, respectively. These results are similar to those of Marin et al. [13] who retrospectively compared the diagnostic efficacy of the fat-only datasets with the corresponding OP/IP datasets of adrenal lesions using a 3 T MR system. In our patients, using the fat/water datasets enabled correct classification of an additional clear-cell renal cell carcinoma metastasis compared with only using the OP/IP datasets.

Although there were no significant differences between the diagnostic accuracy of the chemical shift imaging techniques at 1.5 T and 3 T, the differences in the physics principles of 1.5 T and 3 T affect the optimal threshold values for each chemical shift technique. In addition, the difference in sequence parameters at 3 T significantly affects the SI and optimal threshold values. Because of this, all previously published studies in the literature propose different optimal threshold values for discrimination of adrenal adenomas from non-adenomas when using a 3 T MR unit [7, 8, 12–14]. Radiologist must be aware of these distinctions to avoid misinterpretations.

Our study is limited by several factors. First, the diagnosis of adrenal adenomas was not histologically verified. However, previous literature used the lack of increase in size over 6 months [4, 7, 12, 14, 20, 21] and low density on CT as diagnostic criteria for adrenal adenoma [12, 22]. Second, our sample sizes of non-adenomas and lipid-poor adenomas were relatively small. However, our number of non-adenomas was larger than in previous studies of chemical shift imaging of adrenal lesion at 3 T [7, 8, 12–14]. Third, we were not able to obtain first OP/IP signal of the 2D dGRE chemical shift imaging technique due to hardware limitations of our 3 T MRI unit. Finally, our quantitative assessment depended on the presence of microscopic fat for the diagnosis of adrenal adenoma. However, presence of microscopic fat does not always indicate a benign lesion. Adrenocortical carcinoma, and adrenal metastases from clear-cell renal cell carcinoma and hepatocellular carcinoma may also contain microscopic fat [5, 23, 24].

In conclusion, our study is the first prospective intra-individual comparison study using all previously studied chemical shift imaging techniques at 3 T and the 2D dGRE technique at 1.5 T for discrimination of adrenal adenomas from non-adenomas. Although the 2D dGRE sequence at 1.5 T was more effective than the other chemical shift imaging techniques at 3 T for detecting microscopic fat, there were no significant differences between the diagnostic efficacies of 1.5 T and 3 T chemical shift imaging techniques for distinguishing adrenal adenomas from non-adenomas. 3D sequences (3D VIBE and 3D VIBE-Dixon) can readily differentiate adrenal adenomas from non-adenomas with decreased slice thickness, improved spatial resolution, and high diagnostic accuracy. Because of distinctions in the pulse sequence parameters, optimal threshold values differ for each chemical shift imaging technique. Radiologist should be aware of these details when evaluating adrenal masses on 1.5 T and/or 3 T MR images.

Compliance with ethical standards

Conflict of interest The authors have no relevant financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript.

Institutional review board The institutional review board approved this single-center, prospective, clinical study.

Informed consent Written informed consent was obtained from all patients included in the study.

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