Signature: © Pol J Radiol, 2016; 81: 502-506
DOI: 10.12659/PJR.895868

Polish Journal of Radiology
www.PolRadiol.com
ORIGINAL ARTICLE

Received: 2015.09.04
Accepted: 2016.03.28
Published: 2016.10.25

Evaluation of Free Breathing Versus Breath Hold Diffusion Weighted Imaging in Terms Apparent Diffusion Coefficient (ADC) and Signal-to-Noise Ratio (SNR) Values for Solid Abdominal Organs

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: Our aim was to compare the apparent diffusion coefficient (ADC) values of normal abdominal parenchymal organs and signal-to-noise ratio (SNR) measurements in the same patients with breath hold (BH) and free breathing (FB) diffusion weighted imaging (DWI).

Material/Methods: Forty-eight patients underwent both BH and FB DWI. Spherical region of interest (ROI) was placed on the right hepatic lobe, spleen, pancreas, and renal cortices. ADC values were calculated for each organ on each sequence using an automated software. Image noise, defined as the standard deviation (SD) of the signal intensities in the most artifact-free area of the image background was measured by placing the largest possible ROI on either the left or the right side of the body outside the object in the recorded field of view. SNR was calculated using the formula: SNR=signal intensity $(SI)_{(organ)}$/standard deviation $(SD)_{(noise)}$.

Results: There were no statistically significant differences in ADC values of the abdominal organs between BH and FB DWI sequences ($p>0.05$). There were statistically significant differences between SNR values of organs on BH and FB DWIs. SNRs were found to be better on FB DWI than BH DWI ($p<0.001$).

Conclusions: Free breathing DWI technique reduces image noise and increases SNR for abdominal examinations. Free breathing technique is therefore preferable to BH DWI in the evaluation of abdominal organs by DWI.

MeSH Keywords: **Abdomen • Diffusion • Diffusion Magnetic Resonance Imaging • Magnetic Resonance Imaging**

PDF file: http://www.polradiol.com/abstract/index/idArt/895868

Background

Diffusion weighted imaging (DWI) is a sequence that uses random motion of water molecules in the body to provide images. It depicts the intravoxel incoherent motion of water molecules [1]. After development of rapid imaging techniques like echo-planar imaging (EPI), the extracranial applications of DWI have emerged, and DWI has been shown to be a promising tool, particularly in abdominal imaging [2]. Abdominal organs are difficult to assess by DWI because of motion artifacts caused by breathing and pulsation leading to reduced signal-to-noise ratios (SNR) [3]. Lately, different implementations for abdominal DWI such as breath-hold imaging and non-breath-hold imaging are described [4]. The most commonly used technique for abdominal DWI is reported to be breath-hold single-shot spin-echo echo-planar imaging (SE-EPI) in some studies [4–6]. This technique combined with parallel imaging and fat saturation allows for short acquisition times, covering a large body part in less than 25 seconds (s). But it has disadvantages, like reduced SNR values and increased sensitivity to pulsation and susceptibility artifacts [4].

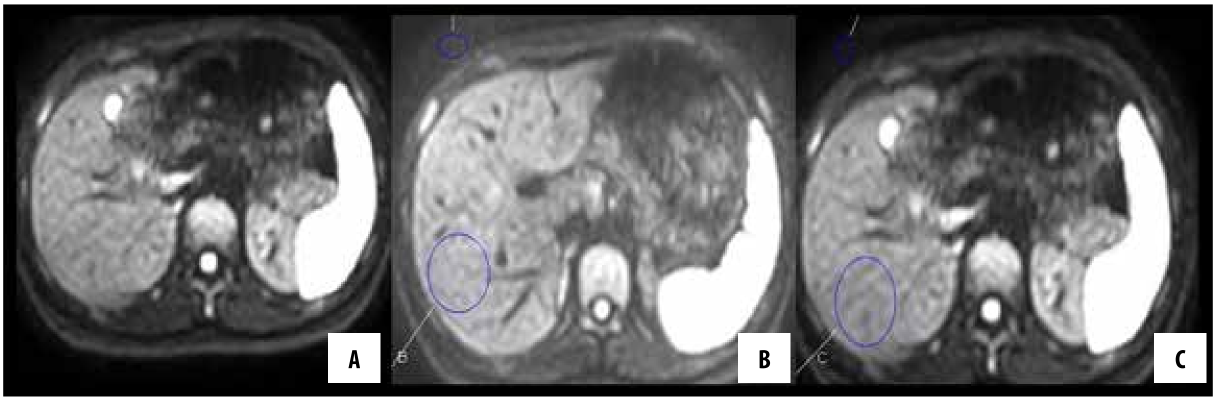

Figure 1. Transverse diffusion-weighted single-shot echo-planar raw image with parallel imaging and fat saturation in a 25-year-old woman (**A**) and signal-to-noise ratio measurements for the liver in breath-hold (**B**) and free breathing (**C**) DWIs at *b* value of 600 s/mm^2. SNR measurements for the liver in BH DWI was 26 and FB was 53.3 for this case.

In this prospective study we aimed to compare SNR values and ADC measurements of normal solid parenchymal organs by using both breath-hold (BH) and free-breathing (FB) DWI combined with the use of parallel imaging and fat saturation and try to determine the best DWI technique for abdominal organs in terms of SNR and ADC, using 1.5 Tesla (T) magnetic resonance (MR) scanner.

Material and Methods

Subject population

This prospective study was approved by the local institutional review board. Written informed consent was obtained from the patients. Study was performed between December 2014 and April 2015. Power analysis was performed for the sample size estimation. Setting type I error (α) at 0.01 and power of the test at 0.95, sample size appropriate to test the hypothesis and have confidence was calculated as 40. Upper abdominal MR imaging (MRI) studies of a total of 120 consecutive patients were evaluated. Oncology (n=35, some with repeated control examinations) and hematology (n=27) patients with known tumors, metastases, hepatomegaly, splenomegaly, hemosiderosis and any other lesions or diseases (n=10) that affect abdominal organs were excluded from the study. Existence of simple renal cortical cysts was not accepted as an exclusion criterion. Forty-eight patients (29 women, 19 men; mean age 64.2; age range 18–84 years) who underwent both BH and FB DWIs and who did not have any lesions as tumors or metastases in their solid abdominal organs were included in the study

MRI technique

Patients underwent MRI examination in a 1.5 T superconducting system (Ingenia, Philips Healthcare, Best, the Netherlands) using an eight-channel phased-array torso coil. Breath-hold and FB EPI combined with parallel imaging and fat saturation were performed starting from the diaphragms to the lower poles of the kidneys, one after one for each patient. Parallel imaging was performed using sensitivity encoding technique (SENSE, Philips Healthcare) with a parallel imaging (PI) factor of two. Diffusion gradients were applied in three orthogonal directions [frequency-encoding (x), phase-encoding (y), and section-select directions (z)] with a *b* value of 600 s/mm^2. Other parameters for BH and FB DWIs were as follows: TR, 1134 ms; TE, 59 ms; matrix, 132×102; FOV, 40×30 cm; bandwidth, 1288 Hz; slice thickness, 6 mm; intersection gap, 0.6 mm; number of signal averages (NSA), 3. The acquisition times were completed in 48 seconds (s) for both BH and FB DWIs. The only difference was that the patients held their breaths in 3 equal acquisition times (3×16 s) for BH DWI technique.

Image interpretation

All images were analyzed and measurements were performed on a work station (Philips Ingenia 1.5T release 4.1.1, Eindhoven, Netherlands) and recorded by a radiologist with a 5-year experience in abdominal MRI. Signal intensity ($(SI)_{(organ)}$) of the organs and standard deviation of the noise ($(SD)_{(noise)}$) were calculated from the raw DWI images taken with the b value of 600 s/mm^2. Apparent diffusion coefficient (ADC) values of the parenchymal organs (liver, pancreas, spleen, right and left kidney separately) were measured from automatically derived ADC maps on the same work station. Signal-to-noise ratio was calculated using the formula: SNR=signal intensity $(SI)_{(organ)}$/ standard deviation $(SD)_{(noise)}$. $SI_{(organ)}$ of the solid abdominal parenchymal organs were measured at *b* value of 600 s/mm^2 on both BH and FB DWI. Spherical regions of interest (ROI) were drawn and placed on the right hepatic lobe (Figure 1), on the mid-body of the spleen and on the upper and lower poles and mid-portions of the cortices of kidneys. Since pancreas was more difficult to evaluate on DWI than other organs, spherical ROI was placed on the visible parts of the pancreatic parenchyma, mostly on the corpus. ROI areas were between 2000 and 500 mm^2 for the liver, 1000–400 mm^2 for the spleen and 60–150 mm^2 for kidneys. ROIs were smaller for the pancreas, ranging between 40 and 70 mm^2. Care was taken to exclude vessels and renal cysts from the ROIs. We applied three ROI measurements for each organ and three measurements for each part of the kidneys, the average of these measurements represented the final SI values and the same applications were done to get the final ADC values of the organs (Figure 2). Image noise was defined as the standard deviation (SD) for the largest possible ROI placed on either the left or the right side of the body outside the object in the most artifact-free area of the image background in the recorded field of view.

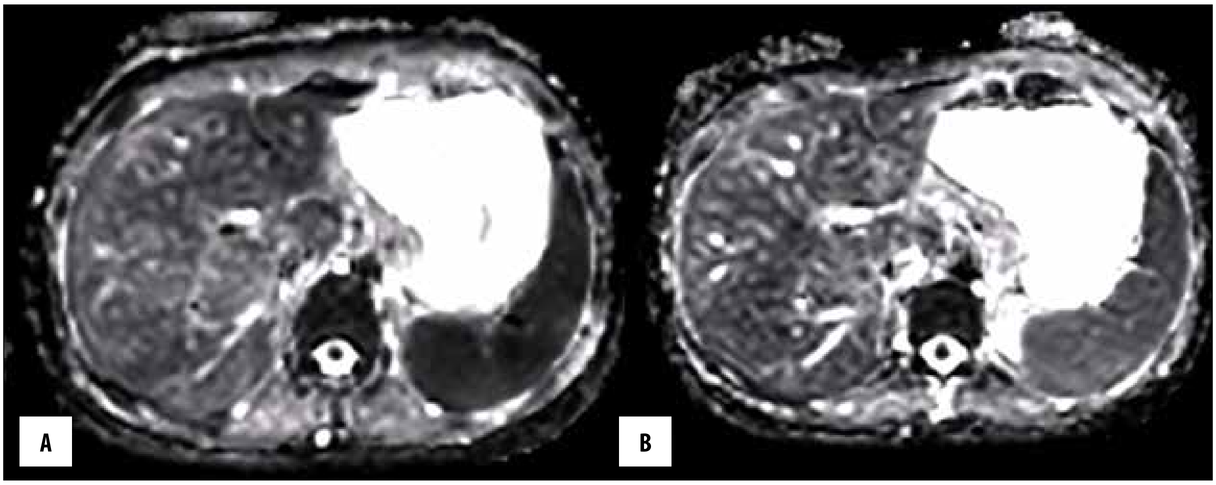

Figure 2. Breath-hold (**A**) and free breathing (**B**) ADC map images of a 25-year-old woman are shown. In this case ADC values were 1.35×10^{-3} mm^2/s for the liver and 1.1×10^{-3} mm^2/s for the spleen in BH DWI and 1.54×10^{-3} mm^2/s for the liver and 1.3×10^{-3} mm^2/s for the spleen in FB DWI.

Table 1. ADC (b=600 s/mm^2) and SNR values of abdominal organs by BH and FB DWI.

Abdominal organ	ADC		SNR	
	BH*	FB**	BH	FB
Liver	$1.53\pm0.17\times10^{-3}$	$1.65\pm0.21\times10^{-3\#}$	53.86 ± 21.75	$79.6\pm25.05^{\#\#}$
Spleen	$1.02\pm0.21\times10^{-3}$	$1.11\pm0.28\times10^{-3\#}$	117.00 ± 38.74	$190.79\pm42.25^{\#\#}$
Pancreas	$1.98\pm0.47\times10^{-3}$	$2.14\pm0.41\times10^{-3\#}$	42.55 ± 18.09	$69.13\pm22.13^{\#\#}$
Right kidney	$2.33\pm0.29\times10^{-3}$	$2.34\pm0.23\times10^{-3\#}$	69.69 ± 21.57	$108.43\pm29.25^{\#\#}$
Left kidney	$2.37\pm0.28\times10^{-3}$	$2.36\pm0.23\times10^{-3\#}$	67.78 ± 19.27	$111.81\pm24.05^{\#\#}$

Data are mean ± standard deviation. ADC – apparent diffusion coefficient; SNR – signal to noise ratio; ADC values were calculated for a *b* value of 600 s/mm^2. * Breath-hold diffusion weighted imaging; ** free breathing diffusion weighted imaging. $^{\#}$ $p>0.05$ compared with BH DWI; $^{\#\#}$ $p<0.001$ compared with BH DWI.

Statistical analysis

Statistical analysis was performed with commercially available statistical software (SPSS 11.0, Chicago, IL, USA). Differences of ADC measurements and SNR values between BH and FB DWI in the same patients were assessed by Wilcoxon signed ranks test. A *p* value of 0.05 or less was defined as significant.

Results

Mean SNR and ADC values of the liver, spleen, pancreas, right and left kidneys were listed in Table 1. No statistically significant differences were observed in ADC values of the abdominal parenchymal organs between BH and FB DWI sequences ($p>0.05$). There were statistically significant differences between SNR values of BH and FB DWIs, with SNR of FB DWI sequences being better than BH DWI sequences ($p<0.01$).

Discussion

Our results show that although ADC values of the normal upper abdominal organs did not differ between BH and FB DWI techniques, SNRs on FB DWI were higher than BH DWI ($p<0.01$). In abdominal MRI applications DWI has become a routinely used sequence in most of the radiology centers. Especially when intravenous contrast media cannot be administered, DWI gains more importance in identifying lesions of the solid abdominal organs. Single shot SE-EPI sequence is reported to be the most efficient technique for abdominal DWI [4,5,7]. Using higher b values (≥500 s/mm^2) to achieve better contrast between tissues breath-hold SE-EPI causes the disadvantage of low SNR values and image distortion in DWI [2,7]. This study reveals that SNR values are lower for BH DWI than FB DWI in abdominal imaging and FB technique might be preferable to breath-holding in routine radiological practice.

Two different b values should be used to get ADC maps as the first one is a low b value (0–100 s/mm^2) and the second is >500 s/mm^2 for abdominal applications [8,9]. In this study we used 0 s/mm^2 and 600 s/mm^2 on both BH and FB DWI. It is known that to minimize misregistration, some background tissue signal is required and b-values of 500–800 s/mm^2 are ideal to separate healthy tissue from restricted tissue while maintaining background tissue signal.

Single shot BH SE-EPI sequence is reported to be the most rapid sequence for DWI but besides its advantages, it is inherently noisy, and to overcome the noise, thicker slice partitions (such as 6–8 mm) are needed. This causes the disadvantage of missing small lesions. Free breathing DWI (FB DWI) yields high SNR values and makes it possible to use thin slice partitions [10]. In their study Baltzer et al. [11] found that more focal liver lesions such as metastases were detected with FB DWI sequence than BH DWI. In a recent study, ADC values of the normal abdominal organs were evaluated with FB DWI combined with parallel imaging [12]. They found ADC values of the anterior and posterior segments of the right liver lobe as $1.46\pm0.18\times10^{-3}$ and $1.34\times0.20\times10^{-3}$ respectively, ADC value of the spleen as $1.28\pm0.38\times10^{-3}$, kidney cortex as $2.08\times0.22\times10^{-3}$ and pancreas head as $1.65\pm0.29\times10^{-3}$, body as $1.68\pm0.26\times10^{-3}$ and tail as $1.59\pm0.38\times10^{-3}$. We also found similar ADC values for the liver, spleen and kidneys on FB DWIs. Although we did not divide pancreas into 3 parts when measuring ADCs, our results for normal pancreas parenchyma were different and our ADC values were greater than their results on FB DWI sequence ($2.14\pm0.41\times10^{-3}$). In another study, which compared normal pancreas and pancreas cancer with respiratory-triggered EPI DWI sequence, ADC value of the normal pancreas was found to be $1.99\pm0.206\times10^{-3}$ mm^2/s [10]. They also applied a high b value (800 s/mm^2) as we did. One study that recently compared ADC values of the normal pancreas and acute pancreatitis with a b value of 800 s/mm^2 showed that normal pancreas had an ADC value of $1.77\pm0.32\times10^{-3}$ mm^2/s [13]. These variations in ADC values of abdominal organs may be because of the effect of b value chosen for the measurements. Another study that measured ADC values in transplanted kidneys by using b values of 600 s/mm^2 and 1000 s/mm^2 revealed that the best quality was achieved in the renal cortex when 1000 s/mm^2 was used [14]. Still, there is no consensus on b value choices for abdominal organs. Many studies in the literature reveal that ADC values of the abdominal organs have a wide range of variety and are mostly affected by the lack of standardization of b value selections [3,13,15]. This study also establishes the same conclusion for ADC values of the normal organs with only one difference that in this study we calculated the ADC values of normal organs with two different DWI techniques and compared them with each other. This result shows that choosing either BH or FB DWI technique in clinical practice will not have an effect on ADC values of the organs. So, according to our findings, both DWI techniques are reliable in the abdomen to evaluate organs when ADC values are taken into account but SNR values are better for FB technique and this is advantageous over breath holding considering also the patients' comfort (there are patients who have trouble in holding their breath). In a study by Baltzer et al. [11] focal liver lesions were compared with BH and FB DWI techniques and small lesions were reported to be missed on BH DWI technique especially because of the effect of low SNR. SNR increases with low b values and affects spatial resolution of DWI and this can be come over by increasing signal averages. In this study we used a moderately high b value (600 mm^2/s), kept the NSA the same for both techniques and found that the SNR of BH DWI was lower than FB DWI. In another study published recently about the detection of extrahepatic cholangiocarcinoma with DWI, SNR and ADC values were measured with a b value of 800 s/mm^2 and that study revealed that although SNRs decreased between normal liver and tumor tissue by a higher b value, tumor SNR was found to increase gradually [16]. Several studies reported that using higher b values causes a decrease in SNR. A study with breast lesions using different b values (600, 800 and 1000 s/mm^2) revealed that SNRs and contrast ratios decrease as b value gets higher but this does not influence the conspicuity of the lesions [17–19]. Although we did not use a very high b value in our study, combining free breathing technique with high b values in DWI might overcome the problem of low SNR and gain importance in abdominal radiology practice.

According to our results combined with the results of the studies in the literature, without changing any variables (NSA, TR, TE…etc.), the use of high b values with free-breathing technique in DWI in the abdomen is preferable, effective and better than BH DWI in terms of higher SNR ratios. So we recommend the use of FB DWI for abdominal MR applications which is also suitable for patients who are not compliant to the examination (who cannot hold breath).

The current study had some limitations. First, we used a moderately high b value (600 mm^2/s) and did not calculate the ADC values of abdominal organs using different b values. So, the effects of different b values on ADC and SNR values on FB and BH DWIs for normal abdominal solid organs are not clear in this study. Second, we did not design this study to compare any focal lesions in abdominal organs with these two techniques, so further studies can be done to evaluate normal abdominal organs and lesions of the abdominal organs to achieve reproducibility of ADC and SNR values by BH and FB DWIs. Thirdly, only one experienced radiologist did the measurements and interobserver comparisons might be better for the reproducibility of the results. Finally, we did not use respiratory gating so we cannot compare these two techniques with respiratory-triggered DWI and do not know the added value or disadvantages of respiratory gating to DWI of parenchymal abdominal organs.

Conclusions

In conclusion, we did not find significant differences in ADC values of the normal upper abdominal organs between FB and BH DWI techniques. However, the SNRs of the abdominal organs were significantly better in FB technique. So we recommend the use of FB technique for DWI of abdominal parenchymal organs. Further studies are warranted to investigate the reproducibility of ADC and SNR values in breath-hold and free breathing DWI techniques for different benign and malignant lesions of solid abdominal organs.

Conflict of interest

The authors declare that they have no conflict of interest.

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