Diffusion-Weighted MR Imaging of Upper Abdomen: Comparison of Breath-Hold, Free-Breathing, and Respiratory-Triggered Techniques in Image Quality and Apparent Diffusion Coefficient (ADC) Stability

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Directed by Professor Jeong-Sik Yu

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ABSTRACT

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Purpose: To compare the image quality and stability of apparent diffusion coefficient (ADC) in the diffusion-weighted MRI (DWI) of upper abdomen among breath-hold (BH), free-breathing (FB) and respiratory-triggered (RT) techniques.

Methods: We analyzed the qualitative and quantitative parameters of 204 consecutive patients who underwent DWI (BH-DWI, FB–DWI or RT-DWI; n=68 in each technique). Qualitative parameters included liver contour, vascular landmarks, intra-slice homogeneity, and inter-slice discontinuity on

DWI with a b-factor of 800 mm^2/s using a 4-grade scale. Quantitative parameters included inter-slice or intra-slice inhomogeneity of ADC in the spleen.

Results: RT-DWI showed better liver contour compared to BH-DWI ($P<0.001$) or FB-DWI ($P=0.001$). Regarding the quality of vascular landmarks, BH-DWI had inferior results compared to FB-DWI ($P=0.025$) and RT-DWI ($P<0.001$). FB-DWI had the poorest result ($P<0.001$) for inter-slice discontinuity compared to the other techniques. FB-DWI showed significantly larger inter-slice differences between the highest and the lowest ADCs in the spleen compared with those of RT-DWI ($P<0.001$). Intra-slice homogeneity was significantly better in RT-DWI and FB-DWI than in BH-DWI ($P<0.001$).

Conclusion: Compared with BH or FB techniques, RT-DWI appears to result in the best imaging by providing better anatomic detail without skipping continuous slices, in addition to more homogeneous ADCs.

Key words : abdomen, liver, spleen, magnetic resonance, diffusion-weighted imaging

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I. INTRODUCTION

In the magnetic resonance imaging (MRI) of the upper abdomen especially for the liver, diffusion-weighted MRI (DWI) has been reported to be useful for the detection and characterization of focal lesions.[1-3] While conventional unenhanced MRI depends on tissue-specific T1 and T2 relaxation times and dynamic MRI depends on arterial hypervascularity, DWI achieves tissue contrast based on tissue differences in the Brownian motion of intra- and extracellular water molecules.[4] Generally, DWI forms images using T2-weighted spin-echo echo-planar imaging (EPI) sequences with two or more different diffusion gradients designated as “b-factors” before and after the 180º refocusing pulses.[5] The apparent diffusion coefficient (ADC) of the target tissue can be calculated by eliminating background T2 effects in order to better characterize a disease process. Various methods have been proposed to achieve high-quality DWI by optimizing the signal-to-noise ratio (SNR) in limited scanning time, reducing the susceptibility artifact of EPI and reducing artifact from inevitable physiologic motion. For clinical imaging of the upper abdomen, three different techniques have been proposed for the daily practice: the breath-hold (BH), free-breathing (FB), and respiratory-triggered (RT) techniques.[6] Although these techniques are widely used in obtaining DWI, there are limited comparative studies dealing with the ADC reproducibility or the image quality.[7,8] Aside of the reproducibility between the different DWI sessions, the stability which means the degree of intra- and inter-slice variability in the same imaging session would be also important to grant a reliability for the measured values of ADC; however there has been no such study dealing with the comparative stability among the different data acquisition techniques of DWI. In the present study, we compared the image quality and ADC stability in the DWI of upper abdomen among the three different methods of data acquisition.

II. MATERIALS AND METHODS

1. Patients

Approval for this retrospective study was obtained from our institutional review board, which waived the requirement of informed consent. We retrospectively analyzed a total of 204 consecutive patients (135 men and 69 women aged from 16 to 86 years old [mean, 59.6]), examined by hepatic MRI using one of the three approaches (BH, FB, or RT), DWI during BH (BH-DWI) was performed between March and May 2007 in 68 patients, DWI during FB (FB-DWI) was performed between August and October 2007, in 68 other patients, and DWI during RT (RT-DWI) was performed between February and April 2008 in the third set of 68 patients. Among the three groups of patients, there were no remarkable differences for the number of cirrhotic and non-cirrhotic patients (Table 1).

Table 1. Patients in Three Groups of Different Diffusion-Weighted MR Imaging Techniques.

	BH-DWI	FB-DWI	RT-DWI
Cirrhotic liver			
with hepatocellular carcinoma	32	41	41
without hepatocellular carcinoma	9	3	2
Non-cirrhotic liver			
no focal lesion	12	17	8

hepatocellular carcinoma	2	0	0
cavernous hemangioma	4	1	2
focal nodular hyperplasia	1	0	3
hepatic abscess	2	0	0
myelolipoma	1	0	0
cholangiocellular carcinoma	0	0	3
metastases from extrahepatic tumor			
colorectal cancer	3	5	6
stomach cancer	0	0	1
pancreas cancer	0	0	1
extrahepatic bile duct cancer	1	0	0
cervix cancer	1	0	0
breast cancer	0	1	0
nasopharyngeal cancer	0	0	1
Total	68	68	68

Numbers are the number of the patients

DWI = diffusion-weighted MR imaging, BH = breath-hold, FB = free-breathing, RT = respiratory-triggered

2. MRI Techniques

The MRI was performed using a 1.5 Tesla (T) system (Magnetom Avanto; Siemens, Erlangen, Germany) equipped with high-performance gradients (maximum amplitude 45 mT/m) and a six-element phased-array surface coil. Patients were positioned supine, with anterior and posterior phased-array coils centered over the liver. After obtaining localizer images in the supine position, spectrally fat-suppressed breath-hold T2-weighted turbo spin echo (TSE) images (repetition time [TR] = 3020 ms, echo time [TE] = 109 ms, flip angle = 150°, echo train length = 13, slice thickness = 6 mm, slices = 21) were obtained in the axial plane. After obtaining a double-echo chemical shift gradient echo sequence (GRE) (TR 100 ms, first-echo TE 2.0 ms [opposed-phase], second-echo TE 4.2 ms [in-phase], flip angle 70°), dynamic contrast-enhanced imaging was performed using a three-dimensional (3D) GRE sequence (VIBE; Siemens, Erlangen, Germany) with ultrafast image reconstruction by parallel imaging algorithms (GRAPPA factor, 2) in the axial plane (TR 4.4 ms, TE 2.1 ms, flip angle 10°, matrix 448 x 224, field of view [FOV], 271 x 379 mm, slice thickness 5 mm, slice spacing 2.5 mm, slices 72) during a 20 s breath-holding period. A dynamic series consisted of one precontrast series followed by three successive postcontrast series including early arterial, late arterial, and portal phase imaging with 34 s intervals (20 s for image acquisition with breath-holding and 14 s for re-breathing) for the start of each phase imaging followed by 5 min delayed phase imaging.

DWI was performed before dynamic imaging using a single-shot spin-echo EPI sequence that combined the two diffusion (motion-probing) gradients before and after the 180° pulse along the three directions of section-select, phase-encoding, and frequency-encoding. Data acquisition with an EPI read-out was obtained by applying three different b-factors of 50, 400, and 800s/mm^2. Common parameters for DWI sequences are as follows. A generalized auto-calibrating partially parallel acquisition (GRAPPA) algorithm of parallel imaging with a twofold acceleration factor was added to reduce acquisition time. Spectral fat saturation was used systematically to suppress chemical-shift artifacts. Technical parameters of BH-DWI were as follows (Table 2): TR 1000 ms, TE 69 ms, matrix 128 x 192, FOV 308-379 mm, slices 27 (9 slices for each b factor), thickness 6 mm, inter-slice gap 1.8 mm, number of excitations = 2, bandwidth 1735 Hz/pixel, acquisition time 24s. The sequence was obtained within a single breath-holding period for the upper half of the liver and another single breath-holding period for the lower half of the liver; a total of 18 slices were acquired in a liver for each b- factor. ADC maps of the isotropic images were automatically acquired. Sequence parameters for FB-DWI different from BH-DWI were as follows (Table 2): TR 3900 ms, TE 75 ms, matrix 156 x 192, slices 90 (30 slices for each b-factor), thickness 6 mm with no inter-slice gap, number of excitations = 5. The acquisition time for the entire liver with three different b-factors was 130 s; other parameters were the same as those for the BH technique. RT-DWI sequence parameters were TR 3900 ms, TE 75 ms, matrix 156 × 192, FOV 360-400, slices 78 (26 slices for each b-factor), thickness 6 mm, inter-slice gap 1.2 mm, number of excitations = 4, bandwidth 1,736 Hz/pixel, acquisition time 4-5 min (Table 2). All scans were sent to the picture archiving and communication system (PACS) for interpretation on PACS workstations.

Table 2. Imaging Parameters of Three Diffusion-Weighted MR Imaging Techniques

	BH-DWI	FB-DWI	RT-DWI
Repetition time (msec)	1000	3900	3900
Echo time (msec)	69	75	75
Matrix size	128 x 192	156 x 192	156 x 192
Field of view (mm)	308-379	308-379	360-400
b-factor (s/mm^2)	50, 400, 800	50, 400, 800	50, 400, 800
Number of excitation	2	5	4
Number of slices	9 x 2	30	26
Slice thickness (mm)	6	6	6
Slice gap (mm)	1.8	0	1.2
Acquisition time	24 sec x 2	130 sec	4-5 min

DWI = diffusion-weighted MR imaging, BH = breath-hold, FB = free-breathing, RT = respiratory-triggered

3. Image Analysis

MR images were reviewed retrospectively by the consensus of three attending radiologists who had 6, 13 and 15 years of experience in abdominal MRI. Each imaging set of diffusion images using b=800 s/mm^2 from the three different DWI techniques was qualitatively evaluated using a 4-grade scale for (a) delineation of the left liver contour (1, poor; 2, fair; 3,good; 4, excellent), (b) sharpness of the intrahepatic vessels of right hemiliver (1, severe blurring; 2, moderate blurring; 3, minimal blurring ; 4, good visualization of the peripheral branch), (c) inhomogeneity of signal intensity across the field of view (1, severe; 2, moderate; 3, mild; 4, no or minor), and (d) inter-slice discontinuity (1, severe; 2, moderate; 3, mild; 4, no or minor). We calculated the average among the three radiologists.

Quantitative comparison of the three techniques was performed by analyzing the ADC values of the spleen, which was empirically selected in this study due to the measurable organ size, less vulnerability to the cardiac or respiratory motion, and internal homogeneity without large intervening vasculature. ADC values of the spleen were calculated from the ADC maps with use of all b factors of 50, 400 and 800 s/mm^2 in each patient using operator-defined region-of- interest (ROI) measurements performed by a fourth-year radiology resident. ROIs were located in the central portion of spleen free from large vessels, any artifacts or focal changes with an approximate size of 75 mm^2 in every slice. Among the measured mean ADCs of all different slices, inter-slice inhomogeneity was determined as the difference between the highest and the lowest ADC values in each patient. For evaluation of intra-slice inhomogeneity, the axial slice of the ADC map showing the maximum diameter of the spleen was chosen to draw the ROI over the largest area possible. Intra-slice image noise was quantified as the standard deviation of the signal intensity measured in the ADC map of the spleen.

4. Statistical Analysis

For statistical analysis of all quality scores, the Kruskal-Wallis test was used for multiple comparisons of nonparametric data sets for the three different techniques. The Mann-Whitney test was also used for each comparison between two techniques in three combinations among the three techniques. ADC values of the spleen for inter-slice and intra-slice inhomogeneity were compared using a one-way ANOVA test for the three different techniques followed by post-hoc analysis (Bonferroni test) for each comparison between two techniques. A P-value less than 0.05 was considered statistically significant.

III. RESULTS

There were significant differences in image quality that included liver contour, vascular landmarks and inter-slice discontinuity ($P<0.001$), while there was no statistically significant difference in intra-slice inhomogeneity ($P=0.166$) among techniques (Figs. 1, 2) (Table 3). Comparison between two techniques showed that RT-DWI resulted in a clearer liver contour compared to BH-DWI ($P<0.001$) and FB-DWI ($P=0.001$). The mean quality score of the liver contour in BH-DWI was comparable to the FB-DWI score ($P=0.684$). The mean quality score of vascular landmarks was lower in, BH-DWI than in FB-DWI ($P=0.025$) or RT-DWI ($P<0.001$), while there was no significant difference between scores in FB-DWI and RT-DWI ($P=0.077$). FB-DWI had the lowest quality score for continuity between slices ($P<0.001$), while BH-DWI and RT-DWI showed similar scores ($P=0.748$) (Fig. 2) (Table 3).

Inter- and intra-slice differences in ADCs measured on the map were significantly different ($P<0.001$) between the three techniques. There was no significant mean inter-slice difference between the ADCs of BH-DWI ($0.420 \pm 0.221 \times 10^{-3}$ mm^2/s) and RT-DWI ($0.349 \pm 0.183 \times 10^{-3}$ mm^2/s) ($P=0.241$) or between those of BH-DWI and FB-DWI ($0.516 \pm 0.294 \times 10^{-3}$ mm^2/s) ($P=0.058$); however, FB-DWI showed a significantly greater inter-slice difference between the highest and lowest ADCs compared to RT-DWI ($P<0.001$) (Fig. 3). The mean standard deviations representing intra-slice homogeneity were smaller in RT-DWI (0.040×10^{-3} mm^2/s) and FB-DWI

(0.044×10^{-3} mm^2/s) than in BH-DWI (0.048×10^{-3} mm^2/s) ($P<0.001$), while there was no significant difference between those of FB-DWI and RT-DWI ($P=0.395$) (Fig. 4).

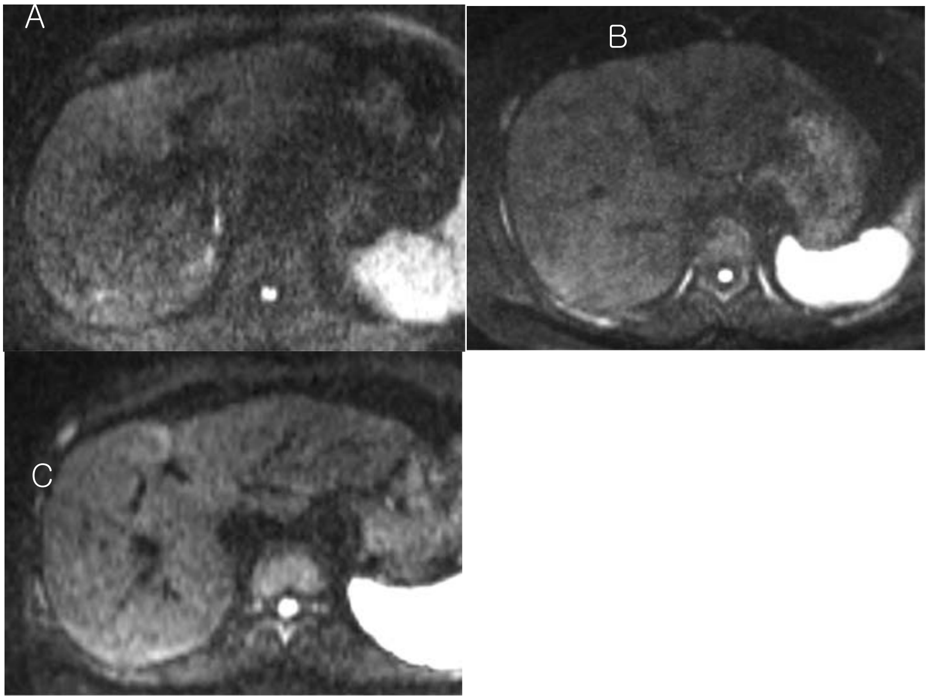

Fig 1. Representative examples of diffusion-weighted MR images of b=800 mm^2/s with breath-hold, free-breathing, and respiratory-triggered methods in three different patients.

A-**C.** Vascular landmarks are poorer on breath-hold image (**A**) due to the lower signal-to-noise ratio compared to the free-breathing (**B**) or respiratory-triggered images (**C**). Respiratory-triggered image (**C**) show better overall image quality in the liver contour especially for the left lobe compared to the other images.

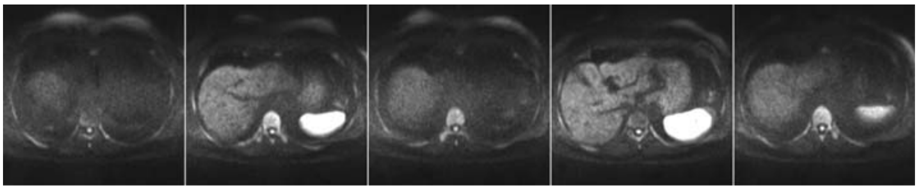

Fig. 2. Representative example of five contiguous slices of diffusion-weighted imaging (b=800 mm^2/s) with use of free-breathing technique in a 64-year-old man with a cirrhotic liver.

A-E. From (**A)** to (**E)**, the axial image slices are markedly discontinuous passing around the liver dome to right hepatic vein level and the signal intensities of the hepatic parenchyma are not homogeneous between the slices due to a serious misregistration effect during the free-breathing.

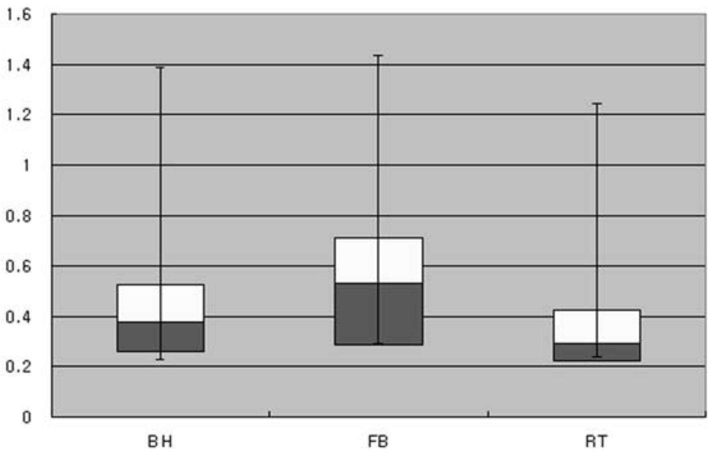

Fig. 3. Box-plots of mean inter-slice differences of apparent diffusion coefficients (ADCs) measured in the spleen on the three diffusion-weighted images of breath-hold (BH), free-breathing (FB) and respiratory-triggered (RT) techniques. The decimal numbers on the y-axis are inter-slice differences

of ADCs (x 10^{-3} mm^2/s). FB shows a significantly greater inter-slice difference between the highest and lowest ADCs compared to RT.

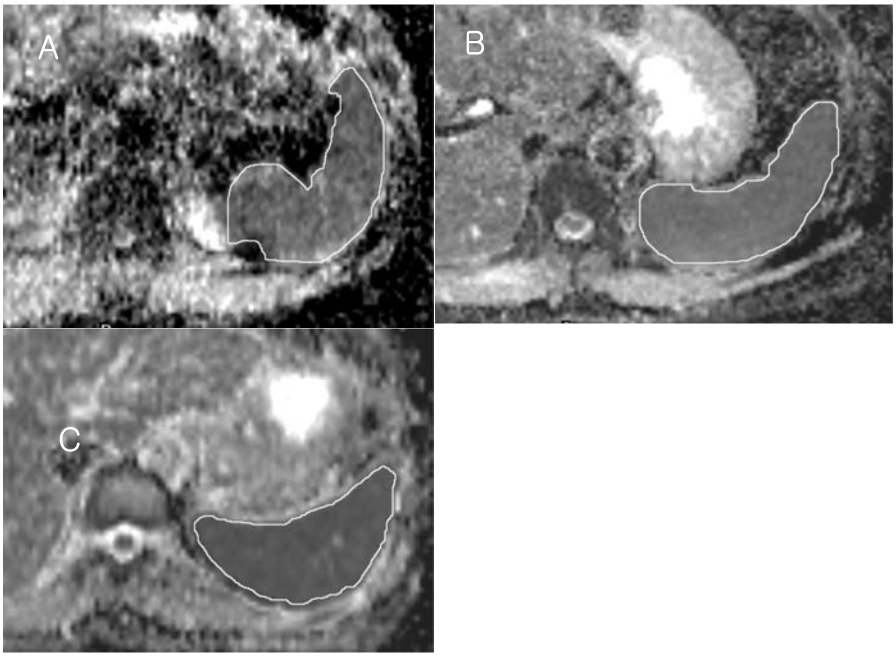

Fig. 4. Representative example of automatically calculated apparent diffusion coefficient (ADC) maps at the level of maximum diameter of the spleens in three different patients.

A-C. Region-of-interest is placed as largest as possible in the spleen in each images and breath-hold image (**A**) shows largest standard deviation compared with free-breathing (**B**) or respiratory-triggered (**C**) images. The standard deviations of ADCs in the above images are as follows: breath-hold, 1.50 x 10^{-3} mm^2/s; free-breathing, 0.88 x 10^{-3} mm^2/s; respiratory-triggered, 0.93 x 10^{-3} mm^2/s.

Table 3. Results of Qualitative Analysis for Three Diffusion-Weighted MR Imaging Techniques Using a 4-Grade Scale for Each Analysis

	BH-DWI	FB-DWI	RT-DWI	P-value*
Liver contour[a]	2.2 ± 1.1	2.3 ± 1.1	2.9 ± 1.0	<0.001
Vascular landmark[b]	2.3 ± 1..2	2.8 ± 1.2	3.2 ± 1.0	<0.001
Intra-slice inhomogeneity[c]	3.2 ± 0.5	3.4 ± 0.8	3.4 ± 0.6	0.166
Inter-slice discontinuity[d]	3.8 ± 0.5	3.4 ± 0.6	3.8 ± 0.5	<0.001

Data are the mean ± standard deviation. Scoring system: 1= poor, 2 = fair, 3 = good, 4 = excellent.

*Kruskal-Wallis test for multiple comparison

[a]RT-DWI shows significantly better quality scores than the other two techniques on Mann-Whitney test (P≤0.001).

[b]BH-DWI shows significantly worse score than RT-DWI (P<0.001) or FB-DWI (P=0.025).

[c]No significant differences in all combination of comparison between two different techniques (P>0.05).

[d]FB-DWI shows worse score than the other two techniques (P<0.001).

DWI = diffusion-weighted MR imaging, BH = breath-hold, FB = free-breathing, RT = respiratory-triggered

IV. DISCUSSION

DWI is a non-enhanced technique that does not require administration of intravenous contrast agent and provides unique tissue contrast that reflects cellularity, the integrity of cellular membranes, and the viscosity of extracellular fluid.[9,10] However, due to DWI's sensitivity to the microscopic motion of water molecules, abdominal imaging is easily affected by physiologic motion such as respiration, bowel peristalsis, cardiac pulsation and blood flow.[11] To minimize the adverse effects from inherent susceptibility artifact and limited signal-to-noise ratio in the EPI sequence and motion-related image degradation, several methods have been introduced for DWI of the liver including BH-, FB- and RT-DWI.[6] The short imaging time required in BH-DWI aims to eliminate respiratory motion, although it also minimizes the number of excitations and thus limits the signal-to-noise ratio (SNR).[12] FB-DWI was originally designed for whole-body DWI with the advantage of a large number of excitations to enhance the SNR and obtain thinner section imaging.[13] Furthermore, the long image acquisition time of RT-DWI can reduce marginal blurring by minimizing physiologic motion and high SNR.[6,7,14,15] All three methods have been used in clinical practice for DWI of the upper abdomen; however, the relative value of each technique's ADC has rarely been addressed in the scientific literature.[7,8] In the present study, we aimed to compare the technical feasibility of the three methods of DWI acquisition by qualitative and quantitative analysis.

As noted in previous reports,[6,12] no single DWI technique satisfies all qualitative or quantitative criteria. Therefore, selection of a DWI technique depends upon its clinical indication and institutional protocol. Nevertheless, our study found significant differences between qualitative and quantitative values of the three different techniques. The key advantages of BH-DWI, which requires a 6 mm or thicker slice to maintain image quality, include short imaging time.[8,12] In our study, even with a slice thickness of 6 mm, BH-DWI had a lower quality of liver contour than RT-DWI in addition to a lower quality of vascular landmarks (b=800 s/mm^2). Although, we did not separately analyze the quality scores for the right and left hemilivers, the pulsatile movement of heart is well-known to degrade the image of the left hemiliver on DWI with large b-factors,[6] which might have influenced the poor overall quality scores of BH-DWI in our study. The poorest overall intra-slice homogeneity of BH-DWI, quantified by the standard deviation on the ADC maps, may also be due to the inherently poor SNR in the present study.

Taking advantage of numerous excitations within a limited imaging time, FB-DWI inherently guarantees a high SNR, enabling thin section imaging with use of multiple b-factors for more accurate ADC calculation.[6,8,12,13] However, our qualitative and quantitative analysis showed the inter-slice variability of FB-DWI was too large to expect a full set of images covering the entire anatomic structure in the imaging fields. This unexpected skip of imaging slices may be due to the inability to fix the exact location of individual slices during breathing in this kind of image acquisition. This drawback seems to be fatal for the assessment of small focal lesions in upper abdominal imaging.[15] The acquisition time of single-shot EPI, which was used for DWI in the present study, is very short. Although an individual image made of one excitation is free of motion effects, more time is necessary for multiple excitations of the same slice to improve SNR of FB-DWI.[12] In this situation, signal misregistration would be inevitable even in the same image slice, which resulted in the blurring of anatomic details and low quality scores of FB-DWI in the present study. Consequently, the ADC may be less accurate and less reproducible in FB-DWI.[6]

At the expense of prolonged examination time, RT-DWI provides sharper anatomic details.[6,8] In the present study, all RT-DWI quality scores, which was relatively free from respiration-related marginal blurring with a high SNR from multiple excitations, were comparable or superior to other techniques. Even though Kwee *et al.*[8] reported ADCs of the hepatic parenchyma to be more scattered in RT-DWI than other techniques, we found the inter-slice difference and inter-slice inhomogeneity of ADCs of the spleen in RT-DWI to be significantly smaller than those in FB-DWI and BH-DWI, respectively. Regarding the ADC measurement in RT-DWI, a pseudo-anisotrophy phenomenon originated in localized hepatic movements during signal acquisition, given that extension, contraction, and rotation are known to accelerate molecular motion.[16] A healthy liver is elastic and easily distorted by slight external forces such as respiratory movement, such movements during RT-DWI in particular have been shown produce higher ADCs.[16,17] In the present study, however, absolute ADCs were not compared between techniques. We also acknowledge that there may be a difference in the elasticity between the liver and spleen, which we used in this study to measure ADC. Our findings of better inter-slice and intra-slice homogeneity of ADCs suggests better reproducibility of the ADC measurement in RT-DWI than in the other techniques, regardless of ADC size.

This study had several limitations. First, the three different techniques were not simultaneously performed or compared in the same patient due to the nature of this retrospective study. However, we contend that the number of patients was large enough to validate the statistical analysis. Second, the spleen was empirically selected for the ADC measurement instead of the liver, which is more often the subject of clinical imaging investigations. We selected the spleen to avoid a partial volume averaging effect by the large hepatic vasculature as well as to prevent image degradation by cardiac pulsation in the left hemiliver. Although the possible difference in elasticity between spleen and liver may have influenced the ADC measurement, splenomegaly caused by liver cirrhosis and portal hypertension would not affect the ADC of the spleen.[18] Absolute value of ADC was out of focus in our study. Moreover, the number of cirrhotic and non-cirrhotic liver was not so different among the three groups of different DWI technique in our study. Although ADCs of the intraabdominal organs would be rather variable even in novel contemporary units,[17] we just used spleen as an organ showing the most homogeneous signal intensity in the upper abdomen[19] for the comparative analysis of the relative inter-slice stability and intra-slice homogeneity among the three different techniques. Third, it may be unfair to compare techniques which used different parameters especially in the number of excitation and scan time. For example, if the scan time were fixed in a short time, the SNR of RT-DWI would be worse than BH- or FB-DWI.[6] However, our study used individually optimized parameters for each technique. Lastly, the results of our study are limited to a 1.5T machine, or even to our specific MRI scanner. High-field units would increase SNR and susceptibility effects, invalidating these results. For example, inherently higher SNR of 3T machine would provide better image quality even in the BH-DWI.[6] To reduce the adverse effect of increased susceptibility for the local magnetic field inhomogeneity in the high field machine, other technical trials of multi-shot EPI or propeller-EPI have been applied for DWI of upper abdomen,[20,21] which are beyond the focus in our study.

V. CONCLUSION

Compared with BH or FB techniques, RT-DWI may provide the best overall image quality, including better anatomic detail, more homogeneous data acquisition for ADCs, and without unexpected skips of continuous slices. Although the imaging time of RT-DWI is far longer than the other techniques, RT-DWI seems valuable enough to be applied for DWI of upper abdomen.

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ABSTRACT(IN KOREAN)

상복부 확산강조자기공명영상: 호흡정지기법, 자유호흡기법, 호흡유발기법간의 비교

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목적: 상복부의 확산강조자기공명영상을 위한 호흡정지기법, 자유호흡기법, 또는 호흡유발기법에서 각 기법간에 상대적인 영상의 질과 겉보기확산계수의 안정성을 평가하고자 하였다.

대상 및 방법: 호흡정지기법, 자유호흡기법, 또는 호흡유발기법을 이용하여 상복부 확산강조자기공명영상을 촬영한 각각 68명씩의 연속적인 환자들을 대상으로 하였다. 간윤곽, 혈관지표, 영상절편내의 균일성, 그리고 영상절편간의 불연속성을 b값 800 s/mm^{2}의 확산강조영상에서 4점 스케일로 질적평가 하였고

영상절편간 혹은 영상절편내의 불균일성을 비장의 겉보기확산계수로 서로 비교하였다.

결과: 간윤곽은 호흡정지기법(P<0.001)이나 자유호흡기법(P=0.001)에 비해 호흡유발기법의 점수가 높았다. 혈관지표는 자유호흡기법(P=0025)이나 호흡유발기법(P<0.001)에 비해 호흡정지기법의 점수가 낮았다. 자유호흡기법은 다른 기법들에 비해 영상절편간의 불연속성이 심각하였으며(P<0.001) 겉보기확산계수도 가장 높은 수치와 가장 낮은 수치간의 차이가 많았다(P<0.001). 호흡정지기법에서 한 절편내의 겉보기확산계수의 균일성이 떨어졌다(P<0.001).

결론: 상복부의 확산강조자기공명영상에 있어 호흡유발기법은 호흡정지기법이나 자유호흡기법에 비해 균일한 겉보기확산계수를 얻을 수 있을 뿐만 아니라 영상절편의 건너뜀이 없이 더욱 우수한 해부학적 정보를 제공할 수 있다.

핵심되는 말 : 복부, 간, 비장, 자기 공명, 확산 강조 영상