ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
Journal of Magnetics 26(3), 294-298 (2021) https://doi.org/10.4283/JMAG.2021.26.3.294

Comparison of an 8-Channel with a 32-Channel Head Coil at 3 Tesla Based on Diffusion-Weighted Imaging with Various b-values: An ACR Phantom Study

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(Received 21 July 2021, Received in final form 9 September 2021, Accepted 10 September 2021)

The purpose of this study was to compare the effect of 8-channel and 32-channel head coils for 3 Tesla brain single shot spin echo diffusion-weighted imaging (DWI) with different b-values. All experiments were performed on a 3 Tesla magnetic resonance scanner using an 8-channel and a 32-channel head coils. The signal-to-noise ratio (SNR), apparent diffusion coefficient (ADC) values, and image distortions were measured with an American College of Radiology (ACR) head phantom. The SNR and ADC values decreased with increasing b-value, and the distortion and image noise increased. In particular, DWI with a b-value ≥ 2000 showed significant noise and distortion for both coils. In conclusion, the use of 32-channel head coils has advantage for brain DWI compared with 8-channel head coils. However, brain DWI with a b-value ≥ 2000 did not statistically improve SNR on 32-channel coils compared with 8-channel coils, and showed a significant noise and distortion for both coils

Keywords : DWI, MR head coil, b-value

1. Introduction

In the field of magnetic resonance (MR) imaging, diffusion-weighted imaging (DWI) using single-shot echo-planar imaging (EPI) is the most commonly used method to diagnose early brain infarction and acute brain stroke. Not only is it fast and relatively insensitive to patient's motions, but it has high sensitivity to acute ischemia and provides useful quantitative information about Brownian motion related to normal or abnormal tissue [1, 2]. The apparent diffusion coefficient (ADC) obtained with DWI is also highly effective to differentiate tumor grades [3]. However, some studies have shown that EPI-DWI provides relatively low signal-to-noise ratio (SNR), resolution, and distortions (such as blur and susceptibility artifact) because of eddy currents and static magnetic field inhomogeneity [4-6].

The recent development of multichannel coil elements led to their increased use in brain MR imaging, as a higher number of head coil elements can increase SNR and spatial resolution. For example, a 32-channel head coil at 3 Tesla provides up to 1.4–3.5-fold SNR compared with 8- or 12-channel head coils [7, 8]. In addition, previous studies report that DWI with a high b-value detects more ischemic regions than that with standard b-value [9-11]. We therefore hypothesized that a 32-channel coil may be used on DWI with high b-value, without significant loss of SNR.

To the best of our knowledge, coil-comparing studies of brain DWI at 1.5 or 3 Tesla are rare [6, 12, 13], with no studies focusing on head coil comparisons for different b-values in combination with 3 Tesla. Therefore, the purpose of this study was to compare the effect of a 32-channel and an 8-channel coil with different b-values at 3 Tesla brain DWI.

2. Materials and Methods

2.1. Phantom study

An MR phantom, accredited by the American College of Radiology (ACR) (JM, Specialty Parts, San Diego, CA, USA), was used for the phantom measurements performed in this study. The inside measures of the ACR phantom were 148 mm in length and 190 mm in diameter. The phantom was filled with a solution of nickel chloride and sodium chloride (10 mM $NiCl_2$ and 75 mM NaCl

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[14]) and was carefully aligned and positioned in the center of each head coil by indicator laser light according to its nose and chin marks. The room temperature (21.0 °C) was maintained to avoid temperature dependence of the quantitative measurements. Given that this was a phantom study, written informed consent was waived.

2.2. MR protocol

All scans were performed on a clinical 3 Tesla MR scanner (Achieva, Philips Healthcare, The Netherlands) using both phased array 8- and 32-channel head coils (Philips Medical System) without in combination with any types of coils. To ensure the stability of coil signal sensitivity, we performed quality assurance including coil signal sensitivity every month. All values were within the manufacturer's specification. The image signal intensity correction mode known as constant level appearance (CLEAR) was applied in either coil. Experimental parameters, including positioning, were kept the same for both coils. Only EPI-DWI sequences were used. DWI with 13 b-values (0, 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2500, and 3000 s/mm^2) were imaged in the axial plane. DWI scanning parameters were as follows: field of view: 250 × 250 × 105 mm; voxel size: 1.95 × 1.97 mm; acquisition matrix: 128 × 126; reconstruction matrix: 256 × 256; flip angle: 90°; time of repetition: 3000 ms; time of echo: 69 ms; slice thickness: 5 mm; slice gap: 5 mm; number of slice: 11; sensitivity encoding acceleration factor (SENSE AF): 2 (P reduction, AP); number of acquisitions: 1; half scan factor: 0.811, gradient mode: default mode; bandwidth: 24.3 Hz. The phase-encoding direction was anterior to posterior. Slice thickness and slice gap were set according to the ACR phantom test guidelines [14].

2.3. Image analysis

The MR imaging data for each b-value was transferred from the picture archiving and communication system into a personal computer. The location of the ACR phantom slice 7–where the phantom is uniform–was used for the SNR analysis. The SNR values obtained with DWI with different coils were calculated using the National Electrical Manufacturers Association subtraction method 1 [15] according to the following equation:

$$\mathrm{SNR} = \frac{S}{\sigma/\sqrt{2}}, \tag{1}$$

where S is the mean signal value of two images and σ is the standard deviation of the subtracted images. S and σ were derived from the same region of interest (ROI) encompassing 75 % on the two images and the subtracted image. The $\sqrt{2}$ factor arises as noise with propagation of error is derived from the difference image [15, 16]. Image analysis was processed with ImageJ (ImageJ v. 1.45; National Institutes of Health, Bethesda, MD, USA).

ADC values obtained with EPI-DWI at different coils were calculated according to the following equation:

$$\mathrm{ADC} = \frac{1}{(b_2 - b_1)} \log_e\left[\frac{S_1}{S_2}\right], \tag{2}$$

where S_1 and S_2 are signal intensities acquired at low b-value, b_1, and high b-value, b_2, respectively. The relative error of SNR values obtained with each b-value at different coil were calculated according to the following equation:

$$\text{Relative error} = \frac{|\text{SNR in 8ch} - \text{SNR in 32ch}|}{\text{SNR in 8ch}} \times 100(\%) \tag{3}$$

The MATLAB (Mathworks Inc., Natick, MA, USA) was used to calculate the structural similarity index (SSIM) for measuring image distortions between the two images obtained at different coils, which ranges between −1 and 1. When two images are nearly identical, their SSIM is close to 1 [17]. SSIM was calculated according to the following equation:

$$\mathrm{SSIM}(x, y) = (2\mu_x\mu_y + \mathrm{C}_1)(2\sigma_{xy} + \mathrm{C}_2) / (\mu_x^2 + \mu_y^2 + \mathrm{C}_1)(\sigma_x^2 + \sigma_y^2 + \mathrm{C}_2), \tag{3}$$

where μ_x, μ_y, σ_x, σ_y, and σ_{xy} are the local means, standard deviations, and cross covariances for image x, y.

2.4. Statistical analysis

The SNR of b-values and ADC values obtained with EPI-DWI at different coils were compared using a paired Student *t*-test, to investigate the effect of changing b-values between the two head coils. Statistical analyses were performed using IBM SPSS Statistics for Windows/Macintosh, Version 21.0 (IBM Corp., Armonk, NY, USA). For all statistical analyses, a two-sided level $P < 0.05$ was considered as statistically significant.

3. Results

The SNR values obtained with EPI-DWI at different coils are shown Table 1. In general, the SNR values of both coils tended to decrease as the b-value increased. The SNR values were higher with the 32-channel than with the 8-channel head coil. Specifically, the SNR of EPI-DWI using 32-channel coil at b = 0 increased 50.6 % relative to an 8-channel coil. The observed SNR values were significantly different between the two coils up to a b-value of 1800 ($p < 0.05$). On the other hand, when for

Table 1. Signal-to-noise ratio (SNR) and error rate obtained with single-shot echo-planar imaging (EPI-DWI) with different coils.

b-value (s/mm^2)	SNR values[a]		Relative error (%)	p-value
	8-channel	32-channel		
0	173.58 ± 0.75	261.58 ± 2.62	50.69	< 0.01
200	132.44 ± 0.43	195.61 ± 2.56	47.69	< 0.01
400	95.98 ± 0.58	140.26 ± 2.39	46.13	< 0.01
600	81.43 ± 0.57	125.81 ± 2.46	54.51	< 0.01
800	63.29 ± 0.28	95.67 ± 1.42	51.16	< 0.01
1000	53.86 ± 0.61	78.87 ± 1.08	46.43	< 0.01
1200	42.45 ± 0.42	57.76 ± 0.77	36.06	< 0.01
1400	32.41 ± 0.36	37.73 ± 0.71	16.41	< 0.01
1600	23.24 ± 0.23	26.28 ± 0.45	13.08	< 0.01
1800	17.86 ± 0.13	18.37 ± 0.65	2.85	0.028
2000	13.74 ± 0.11	14.11 ± 0.24	2.69	0.160
2500	8.81 ± 0.04	8.87 ± 0.05	0.68	0.056
3000	7.88 ± 0.05	7.93 ± 0.04	0.63	0.061

[a]Results presented as mean ± standard deviation.

Table 2. Apparent diffusion coefficient (ADC) obtained with single-shot echo-planar imaging (EPI-DWI) with different coils.

b-value (s/mm^2)	ADC values (10^{-3} mm^2s^{-1})		p-value
	8-channel	32-channel	
0 and 200	2.030 ± 0.001	2.101 ± 0.003	< 0.01
0 and 400	2.004 ± 0.001	2.068 ± 0.004	< 0.01
0 and 600	1.996 ± 0.001	2.056 ± 0.002	< 0.01
0 and 800	1.992 ± 0.001	2.050 ± 0.002	< 0.01
0 and 1000	1.990 ± 0.001	2.047 ± 0.002	< 0.01
0 and 1200	1.987 ± 0.001	2.045 ± 0.002	< 0.01
0 and 1400	1.985 ± 0.001	2.042 ± 0.002	< 0.01
0 and 1600	1.981 ± 0.001	2.038 ± 0.002	< 0.01
0 and 1800	1.977 ± 0.001	2.029 ± 0.001	< 0.01
0 and 2000	1.965 ± 0.001	2.018 ± 0.01	0.092
0 and 2500	1.849 ± 0.001	1.853 ± 0.002	0.213
0 and 3000	1.592 ± 0.001	1.621 ± 0.003	0.057

Results presented as mean ± standard deviation. ADC values were obtained with signal intensity of acquired at b-value = 0 and high b-value, respectively.

Table 3. Structural similarity index (SSIM) values obtained with different b-values between two coils.

b-value (s/mm^2)	8-channel	32-channel
0	0.9859 ± 0.0011	0.9859 ± 0.0011
200	0.9912 ± 0.0012	0.9912 ± 0.0012
400	0.9492 ± 0.0036	0.9492 ± 0.0036
600	0.9032 ± 0.0053	0.9032 ± 0.0053
800	0.8841 ± 0.0061	0.8841 ± 0.0061
1000	0.8578 ± 0.0056	0.8578 ± 0.0056
1200	0.8108 ± 0.0046	0.8108 ± 0.0046
1400	0.8056 ± 0.0034	0.8056 ± 0.0034
1600	0.7893 ± 0.0026	0.7893 ± 0.0026
1800	0.7508 ± 0.0017	0.7508 ± 0.0017
2000	0.7452 ± 0.0014	0.7452 ± 0.0014
2500	0.7391 ± 0.0003	0.7391 ± 0.0003
3000	0.7371 ± 0.0011	0.7371 ± 0.0011

The SSIM values were the same whether images obtained with an 8 channel head coil or a 32 channel head coil were used as the reference image. When two images are nearly identical, their SSIM is close to 1.

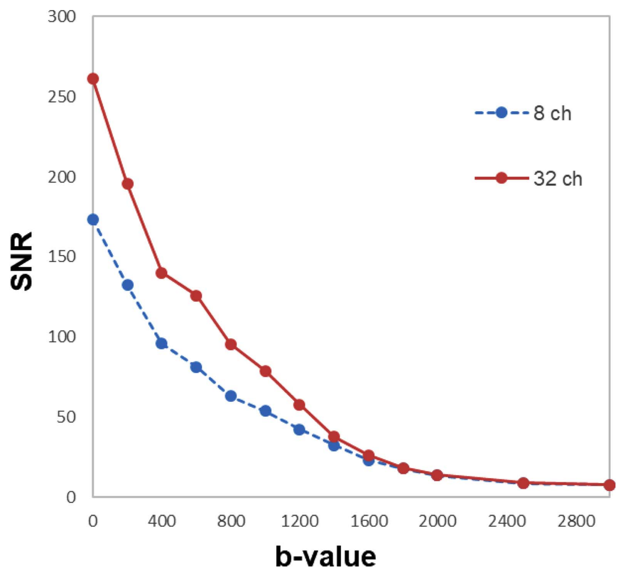

Fig. 1. The signal-to-noise ratio (SNR) as a function of the different b-values.

b ≥ 2000, no significant differences between the two coils were observed regarding the SNR value ($p > 0.05$), as well as a significant reduced relative error.

Table 2 shows the ADC values calculated from EPI-DWI using both coils at b-values of 0–3000. The ADC values decreased as the b-value increased. Up to ADC values obtained at b = 0 and b = 1800, there was statistically significant difference between the two coils ($p < 0.05$), whereas for ADC values higher than those obtained at b = 0 and b = 2000, no significant difference between the two coils was observed ($p > 0.05$).

Table 3 indicates the image distortion as expressed in SSIM. As the b-values increased, the image distortion was found to be increased in DWI between an 8-channel and a 32-channel head coils. Figures 1 and 2 show the SNR value and ADC value obtained with EPI-DWI. The ADC value obtained at b = 0 and b ≥ 2500 was markedly degraded (Fig. 2). Images of EPI-DWI with various b-values are shown in Fig. 3. Significant increased image noise was observed at b-value ≥ 2000.

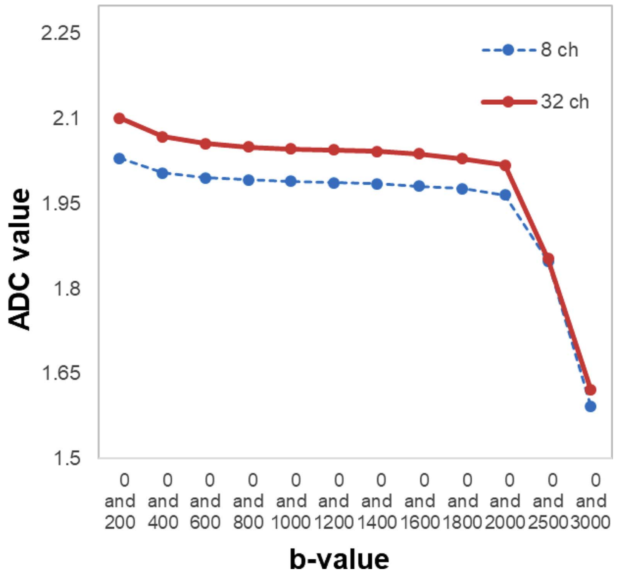

Fig. 2. The apparent diffusion coefficient (ADC) values as a function of the different b-values.

4. Discussion

The present study evaluated the effects of different b-values in brain DWI using two head coils, by determining the SNR and ADC values. Previous studies showed that the signal improvement was at least 1.4- to 3.5-fold higher in the 32-channel head coil relative to 8- or 12-channel head coils [7, 8]. Despite the fact that the sequences used in our experiment differed from those of previous studies, we showed that the SNR increases with the number of phased array coils, which is consistent with their results. However, the SNR improvement did not increase as much as expected, with no statistically significant differences observed for the SNR at DWI with $b \geq 2000$ between two head coils. Although the signal uniformity correction CLEAR mode provided by manufacturer were used to allow improvement in image intensity uniformity, the image noise and distortions at $b \geq 2000$ were so severe that it was difficult to distinguish images (Fig. 3). In addition, the improvement in SNR achieved with its use was lower than expected for the comparison between 8- and 32-channel head coils. Nevertheless, this was the first valuable study investigating how the number of phased array coils affects different b-values, by comparing brain EPI-DWI with 8- and 32-channel head coils.

Some researchers have reported that DWI with high b-value is superior to DWI with standard b-value in the differentiation of cancer grading and acute stroke detection [3, 9-11, 18]. Contrary to their results, this study indicates that there was a significant image noise and distortion in the DWI with $b \geq 2000$ for both coils. However, results from this and previous studies are not fully comparable, because our experiments are based on an ACR phantom (slice 7) that contains a uniform section. Moreover, the use of different ROI location, size, and image parameters

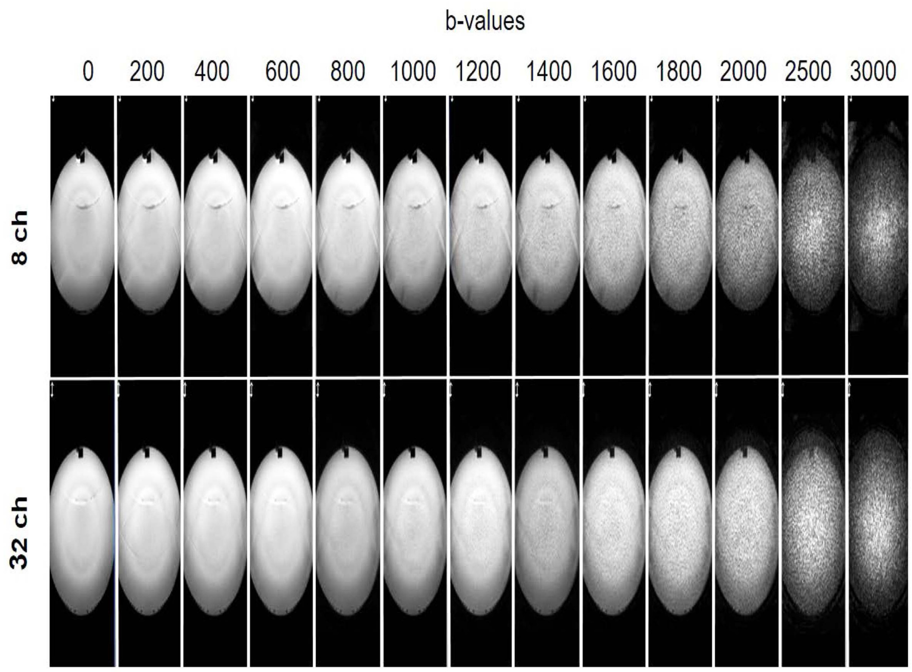

Fig. 3. The DWI images obtained with an 8- and a 32-channel head coil according to different b-values.

may cause this difference.

Our study has some limitations. First, in the DWI sequence, not only quantitative analysis but also qualitative analysis is an important part in clinical practice. However, this experiment was based on an ACR phantom, which is widely used for quality assurance, mechanical performance testing, and does not express lesions with the diversity of ADC value, such as acute stroke and glioma. Thus, there was a limit to the qualitative analysis in our experiment using only ACR phantom. Second, the gradient mode effects on image quality in the DWI sequence. Although a variety of gradient modes provided by vendor were not used in our experiment, we selected a proper default gradient mode based on a previous study on effect of gradient linearity on image quality [19]. Lastly, our experiment was conducted using only one type of MR scanner at a single center. Previous studies have reported that diverse equipment and tesla have different effects on SNR and ADC values of DWI [20, 21]. Therefore, further studies should be performed taking the type of MR scanner and tesla into account. Nevertheless, this was the first study representing the difference in image distortion, SNR, and ADC values obtained with different b-values on brain DWI, based on the comparison of 8- and 32-channel head coils. This study used an ACR phantom, which is widely available, and provided reference information for further research related to effect of increasing the multichannel coil elements on the image quality of DWI sequence with high b-value.

5. Conclusion

In conclusion, the use of 32-channel head coils for brain DWI has advantages as compared with 8-channel head coils. However, brain DWI with a b-value ≥ 2000 did not statistically improve SNR on 32-channel coils compared with 8-channel coils, and showed a significant noise and distortion for both coils.

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