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Standardizing Display Conditions of Diffusion-weighted Images Using Concurrent b0 Images: A Multi-vendor Multi-institutional Study

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Purpose: To establish a practical method that uses concurrent b0 images to standardize the display conditions for diffusion-weighted images (DWI) that vary among institutions and interpreters.

Method: Using identical parameters, we obtained DWI for 12 healthy volunteers at 4 institutions using 4 MRI scanners from 3 vendors. Three operators manually set the window width for the images equal to the signal intensity of the normal-appearing thalamus on b0 images and set the window level at half and then exported the images to 8-bit gray-scale images. We calculated the mean pixel values of the brain objects in the images and examined the variation among scanners, operators, and subjects.

Result: Following our method, the DWI of the 12 subjects obtained using the 4 different scanners had nearly identical contrast and brightness. The mean pixel values of the brain on the exported images among the operators and subjects were not significantly different, but we found a slight, significant difference among the scanners.

Conclusion: Determining DWI display conditions by using b0 images is a simple and practical method to standardize window width and level for evaluating diffusion abnormalities and decreasing variation among institutions and operators.

Keywords: ***b0 image, diffusion-weighted image, display condition, standardization***

Introduction

Diffusion-weighted images (DWI) are widely used to evaluate patients with acute ischemic stroke and other disorders.[1] Unlike T_1- or T_2-weighted images, DWI have no structures that show stable contrast because of the application of motion-probing gradients (MPG). This inconstancy can cause significant variations in DWI display conditions among institutions or operators and may influence the conspicuity of subtle changes in signal and in judgment regarding extent of lesion.

We propose an easy-to-use method employing concurrent b0 images as a reference that can be used even in emergency settings to decide the window width and level for DWI, and we attempt to determine its usefulness to equalize DWI contrast and brightness among scanners, operators, and subjects.

Materials and Methods

After approval from the institutional review boards and written informed consent from all volunteers, we prospectively examined 12 healthy volunteers (7 men, 5 women; aged 27 to 44 years, mean age 33.2 years) at intervals of less than 2 weeks, using three 1.5T and one 3T MR imaging scanner provided by 3 vendors in 4 institutions.

The 4 scanners used were: (A) Signa MR/i with a quadrature detection coil, maximum gradient

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strength of 33 $mT \cdot m^{-1}$, and slew rate of 120 $T \cdot m^{-1} \cdot s^{-1}$ (GE, Milwaukee, WI, USA); (B) Magnetom Symphony with a quadrature detection coil, 30 $mT \cdot m^{-1}$ and 216 $T \cdot m^{-1} \cdot s^{-1}$ (Siemens, Erlangen, Germany); (C) Gyroscan Intera with a multi-channel coil, 33 $mT \cdot m^{-1}$ and 160 $T \cdot m^{-1} \cdot s^{-1}$ (Philips, Best, the Netherlands); and (D) 3T Signa Excite HD with a multi-channel coil, 40 $mT \cdot m^{-1}$ and 150 $T \cdot m^{-1} \cdot s^{-1}$ (GE, Milwaukee).

The pulse sequence used for the DWI was the single-shot spin-echo echo-planar imaging technique with parameters: repetition time, 4000–8000 ms; echo time, 70–100 ms; b value, 1000 s/mm^2; field of view, 220 mm; matrix size, 128×80–128; slice thickness, 6 mm with 0.6- to 2-mm intersection gaps; and two averaged. We obtained 16 to 20 contiguous axial sections parallel to a line through the nasion and the pontomedullary junction, and parallel imaging techniques with a sensitivity-encoding factor of 2 were used with scanners C and D (signal inhomogeneity correction could only be applied in scanner C). The acquired data were anonymized and collected in the Digital Imaging and Communications in Medicine (DICOM) format.

We applied an original method in which window width and level for the DWI were set perthe following equation: window width = SI_{b0}, window level = $(SI_{b0})/2$, where SI_{b0} is the signal intensity in the normal-appearing thalamus as observed from the b0 images. This method is easy to use and can generate contrast and brightness that inversely reflects the ratios of the MPG-related signal reduction of normal-appearing brain tissue. Using a DICOM viewer (ExaVision Lite, Ziosoft, Tokyo), 3 radiologists manually measured the signal intensity of the normal-appearing thalamus on the b0 images by using a mouse-driven cursor for determining a circular region of interest (ROI), and they set the window width/level according to the above-cited method. They then exported the image through the mid-portion of the basal ganglia and thalamus into an 8-bit gray-scale bitmap file. Using commercial graphic software (Photoshop, Adobe, San Jose, CA, USA), one of the authors automatically extracted objects of the entire brain from the exported images by thresholding, and we calculated their mean pixel values.

The differences in mean pixel values of the brain objects among the scanners, subjects, and operators after normalization of display conditions were examined using 2-way repeated measures ANOVA and post hoc Tukey tests. The alpha level used was 0.05.

Results

According to our standardization method, the DWI display conditions were easily set for all subjects. Contrast and brightness of generated images were nearly identical among the scanners, subjects, and operators (Fig. 1).

Quantitative analysis demonstrated that the mean pixel values for the 12 subjects ranged from 104 to 136 (mean ± standard deviation: 117 ± 9) with operator A, 104 to 139 (117 ± 9) with operator B, and 105 to 136 (117 ± 7) with operator C; further, these values ranged from 112 to 120 (117 ± 3) with scanner A, 106 to 114 (108 ± 3) with scanner B, 109 to 118 (115 ± 3) with scanner C, and 119 to 136 (129 ± 5) with scanner D (Fig. 2).

Although we found no statistical differences in the mean pixel values among the subjects ($P = 0.48$, 2-way repeated measures ANOVA) and operators ($P = 0.90$), we noted a significant difference among the scanners ($P < 0.01$). Although no statistical difference was found in the mean pixel value between scanners A and C, the mean pixel value of scanner B was significantly lower ($P < 0.01$, Tukey test) and that of scanner D was significantly higher ($P < 0.01$) than those of the other scanners.

Discussion

DWI have recently been applied as inclusion/exclusion criteria or surrogate outcome measures in multi-center clinical trials of thrombolytic therapy,[2–4] in which interpretation of the extent of acute ischemic lesions on DWI is crucial for deciding indications or estimating the tissue at risk. However, optimal DWI display conditions for judging lesion extension have not been suggested.

DWI display conditions seem to vary among institutions and operators because of the lack of a high-signal anatomical structure that can be used as a reference. In general, operators or interpreters tend to narrow or widen the window to increase the conspicuity of faint lesions or prevent halation of evident lesions. This diversity in display conditions may cause variation in interpretation of the extent of diffusion abnormalities as well as misinterpretation of lesions and artifacts. Although apparent diffusion coefficient (ADC) maps are commonly utilized for quantitative evaluation,[1,5] no standard method to determine the window width and level for DWI has been proposed. In addition, window techniques automated in the consoles of commercial scanners supposedly fail to normalize the display conditions because DWI histograms dramatically differ among images of lesions with and

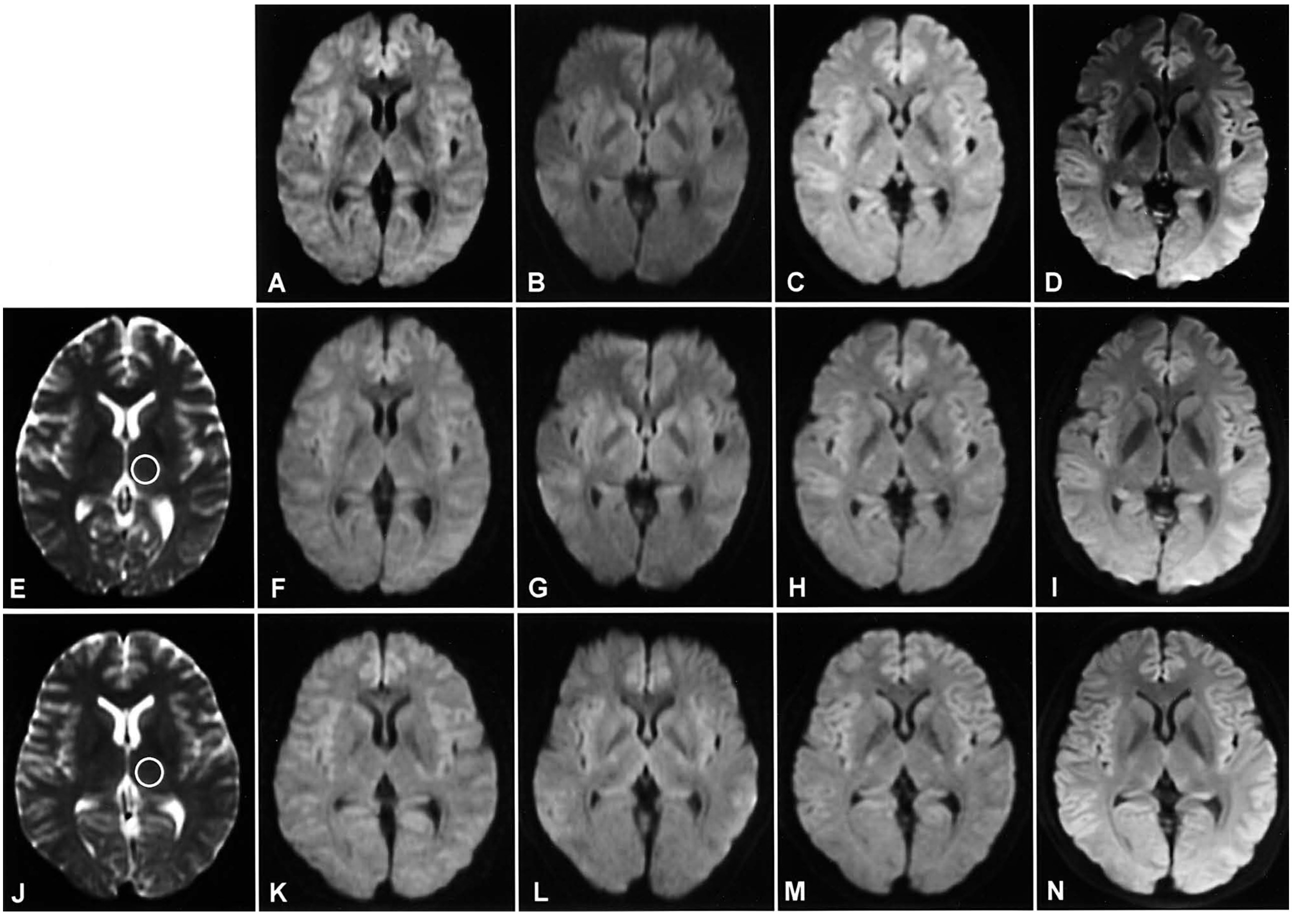


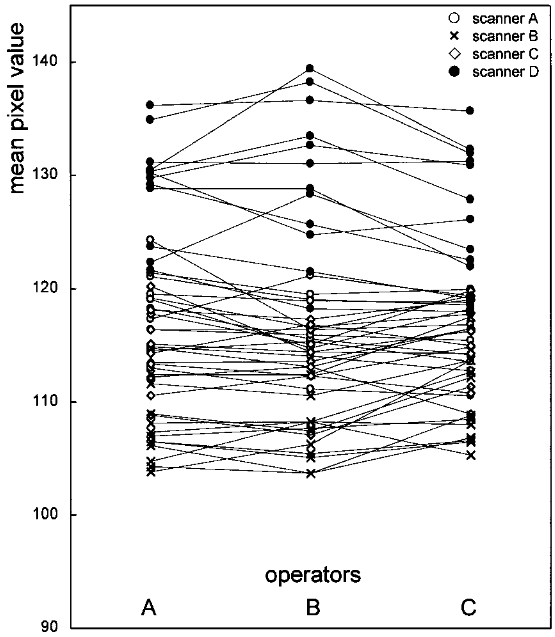
Fig. 1. Diffusion-weighted images (DWI) of 2 subjects by 4 scanners before and after applying the method standardizing display conditions. **(A-I)** 36-year-old woman; **(J-N)** 37-year-old man; **(A-D)** DWI before standardization; **(F-I, K-N)** DWI after standardization; **(E, J)** b0 images; **(A, E, F, J, K)** scanner A; **(B, G, L)** scanner B; **(C, H, M)** scanner C; **(D, I, N)** scanner D. Window width and level of DWI were determined using the signal intensity of the thalamus on concurrent b0 images **(E, J**, circle). Contrast and brightness of the brain tissue on generated images are nearly identical among subjects and scanners **(F-I, K-N)** as compared with those on images before applying the technique **(A-D)**.

without high signal intensity.

To standardize DWI display conditions, we proposed a practical method that is feasible even in emergencies. Because of ROI-based manual measurement, this method may be slightly operator dependent, but it can be performed rapidly with every commercial scanner and workstation. In this study, all operators easily familiarized themselves with the method and performed it within one minute. Moreover, image contrast and brightness generated by this method were visually nearly identical among the scanners, subjects, and operators. Quantitative measurement also revealed no significant difference among the subjects and operators. Thus, this technique is not only easy to use but also reliable for normalizing DWI display conditions.

Quantitatively, we found slight but statistically significant variation among the scanners. We speculate that the reason underlying the variance between scanners A and C and scanner B is a difference in susceptibility-related geometric distortions and artifacts caused by the reversed polarity of the read-out gradient.[6,7] We also assume that the high pixel values, especially in the cortical areas observed with scanner D, are caused by signal inhomogeneity from the uneven sensitivity of the multi-channel coil.[8,9] Although this method cannot fully compensate for machine-dependent issues, we believe that it can yield sufficient results if the gradient polarity is the same and appropriate signal correction techniques are used, such as in scanners A and C.

The technique we propose may be effective for assessing early ischemic lesions in acute ischemic stroke, in which the therapeutic time window is very narrow and the signal intensity of the lesions varies,[10,11] although we did not investigate this in the present study. This technique has been adopted



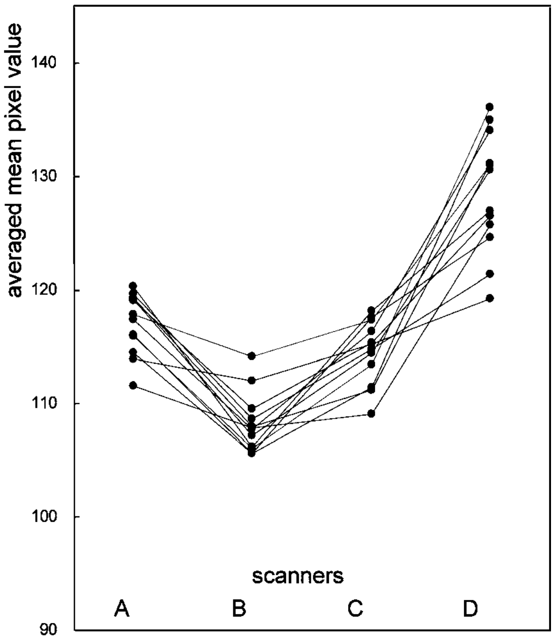


Fig. 2. Mean pixel values of brain subjects on images generated with the standardized window width/level settings. The mean pixel values of the subjects are within the same range among operators **A**, **B**, and **C** (left graph). The averaged mean pixel values are significantly lower in scanner **B** and higher in scanner **D** than in other scanners, whereas those between scanners **A** and **C** are almost the same.

in ongoing multi-center trials concerning thrombolysis and has been implemented in consoles and software of several vendors (unpublished data). Using this method, the conspicuity and extent of lesions can be normalized independent of the scanners, institutions, and operators/interpreters, and standardized interpretation in clinical practice as well as multi-center trials can be achieved; however, further investigation is needed to prove this speculation.

In this method, we selected concurrent b0 images rather than DWI as a reference, because we speculated that the images generated by this technique can be used for semi-quantitative assessment of the ADC, which is said to predict patient outcome and major complications of acute ischemic stroke.[12–14] The pixel values of the brain tissue in the generated images are expected to be roughly proportional to the exponential function of the ADC when there is no alteration in the signal on the b0 images. We chose the thalamus as a reference structure on the b0 images because it is large enough to measure. Thus, when there is an abnormality within the thalamus, we have to substitute other normal-appearing structures for reference. We proposed this method assuming its application to acute stroke imaging. When applying this method to other disorders, young patients, images with b values other than 1000 s/mm^2, or techniques other than SE-EPI, coefficients of the equation should be optimized or other standardization methods considered.

In conclusion, the method we developed to determine window widths and levels by using b0 images can reduce variation in DWI display conditions among subjects, operators, and scanners and be used in clinical practice including emergencies as well as in multi-center clinical trials for acute ischemic stroke.

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