Application of Diffusion Weighted Imaging with Background Body Signal Suppression in Brain Neurography

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ABSTRACT

This study focused on the application of diffusion weighted imaging with background body signal suppression (DWIBS) in brain imaging. Diffusion weighted images with high b value were obtained by combining short T1 inversion recovery, sensitivity encoding technique and echo-planar imaging. Without reducing the signal-to-noise ratio (SNR), the acquisition time of unilateral motion probing gradients (MPGs) DWIBS sequences was controlled within 3 min. The sequences were then compared against the conventional 2D fat-suppressed T2WI. The proposed method enabled the combined use of DW-MR sequences and conventional MR sequences. For this reason, DWIBS is the most popular imaging technique so far, which facilitates the scan speed and reduces the scan time to about 1/3 of the time using conventional technique. Moreover, DWIBS can remove the influence of motion artifacts and increase the spatial resolution of images. By reducing background noises, DWIBS increases the image contrast and the quality of 3D whole-body diffusion weighted images.

Key Words: Brain Neurography, Background Signal Suppression, Diffusion Weighted Imaging

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Introduction

Diffusion-weighted MR neurography (DW-MRN) is based on diffusion weighted imaging with background body signal suppression (DWIBS). DW-MRN involves thin slab acquisition and reconstructs the 3D images via maximum intensity projection (MIP). Gao *et al*., (2006) and Takahara *et al*., (2008) applied DW-MRN to brachial plexus. Their studies demonstrated that DW-MRN not only provided a clear 3D stereoscopic view of the normal brain nerves, but also determined the position and nature of neuropathy. DW-MRN has the advantages of high contrast between the nerves and surrounding soft tissues, satisfactory background suppression and fast 3D neurography.

So far DW-MRN is mainly applied in the imaging of brachial plexus and lumbosacral nerve, and few reports have dealt with the use of DW-MRN for brain neurography. This is exactly what we have done in the present study. Hahn (1950) was the first to note the influence of water diffusion on MRI signals. Stej-skal and Tanner (1965) first described the DWI sequences. DWI is the technique which measures the displacement of water molecule within a certain time and along one specific direction by applying a gradient field (diffusion gradient) symmetrically around the 180° pulse. DWI was first applied in clinical practice in 1986, and the level of diffusion weight is indicated by b value (diffusion sensitivity coefficient): b= (8A) (Δ-8P3). Under physiological conditions, b value for the water molecules

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moving in the extracellular space is influenced by hydraulic pressure, concentration, osmotic pressure, temperature, and geometric shape of extracellular space. Therefore, the movement velocity of water molecules can be hardly measured precisely with DWI, and apparent diffusion coefficient (ADC) is usually calculated instead. In recent years, DWI has been increasingly applied to the brain, lymph nodes and tumor of the whole body. ADC of the living tissues is influenced by multiple factors related to microcirculation, including capillary perfusion, liquid movement and permeability of the cells (Chhabra *et al.,* 2011; Vargas *et al*., 2010; Chhabra *et al*., 2011; Tagliafico *et al*., 2011; Willinek and Schild, 2008; Koh *et al*., 2011). It is also influenced by macroscopic factors, such as respiration, vascular pulsation, and intestinal peristalsis. For whole-body DWI, the influence of physiological movement must be overcome while ensuring the sensitivity to microscopic movement. Breath-hold scan can help prevent artifacts caused by gross movement. But due to the limited scanning time of holding breath, thin slab DWI cannot achieve a sufficiently high SNR. As a result, respiration has a large impact on chest and abdominal scan, and DWI is not fit for extensive scan of the chest and abdomen.

DWIBS was developed by Japanese scholar H.J in 2004 and initially applied to the imaging of tumor and lymph nodes. DWIBS combined with fat suppression is free from the influence of respiration and the constraint of scan time. This method is not only applicable to the brain, but also to the chest, abdomen, pelvic cavity or even the whole body. The core techniques used in DWIBS include the followings: echo planar imaging (EPI), short TI inversion recovery (STIR) (Takahara *et al*., 2004), and sensitivity encoding (SENSE). EPI is the fastest MR imaging technique and can remove the motion artifacts of the whole body. However, EPI is very sensitive to magnetic susceptibility artifacts and usually contains severe chemical shift artifacts. The combined use of EPI and parallel acquisition technique SENSE can facilitate the scan speed and reduce the scan time to about 1/3 of the time using the conventional method. The combined approach removes the influence of motion artifacts, increases the spatial resolution of the images and ensures the quality of whole-body DWI (Dong *et al*., 2015; Kwee *et al.,* 2008; Vargas *et al*., 2010; Yang *et al*., 2011; Jambawalikar *et al*., 2010; Tang and Chen, 2016; Zhou *et al*., 2012). DWIBS is very sensitive to tumor metastases of the whole body and therefore useful for detecting small metastatic foci. As found in a large number of cases and comparison with PET, the coincidence rate of DWIBS with PET in diagnosing metastatic foci has reached over 90%. DWIBS has been used in the imaging of nerves of the four limbs, but the application to brain imaging is rarely reported. In this study, DWIBS was used for brain imaging of 39 volunteers.

Methods

Subjects

The prospective design was approved by the hospital ethics committee. All subjects signed the informed consent (or by parents of one under-age patient). A total of 39 healthy volunteers (31.1±9.5 years; 24-61 years old, 20 males and 19 females) as well as 14 patients with suspected cranial nerve lesions (32.2±15.9 years; 6-61 years old, 10 males and 4 females) were recruited. The cases received unilateral MPGs DW-MRN. None of the healthy volunteers had history of nerve-related disorders. Twenty-one cases received scan of the olfactory nerve, among which 7 cases received scan of the ophthalmic nerve, 7 cases trigeminal nerve, and 7 cases facial nerve; 18 cases received scan of the glossopharyngeal nerve, among which 9 cases received scan of the vagus nerve and 9 cases ophthalmic nerve. Three patients in the case group received follow-up visits at 2 months, 5 months and 1 year after surgery, respectively.

Scan method

Image acquisition

Philips Achieva3.0T TX MR system was used for the scan, with maximum field strength of 80mT-m. This system uses dual-source parallel radiofrequency excitation. The chFlex-L or 8-chKnee coil was used for examination of the olfactory nerve (head first, unilateral imaging). 16-chTorsoXL coil was used for examination of the vagus nerve, and 16-chNV coil for examination of the ophthalmic nerve (unilateral imaging). To visualize bilateral glossopharyngeal nerve lesions in patients with neurofibromatosis, 16-ch Torso XL coil was used for the examination of the ophthalmic nerve and facial nerve. To ensure the consistency of imaging parameters, MPGs were only applied to the DWIBS sequences in two directions (back and forth). Each case was first scan to obtain the orientation, and shimming was conducted to make the main magnetic field more homogenous. Parameters of DWIBS imaging using 2-ch Flex-L and 8_ch Knee coils

were as follows: short T1 inversion recovery echo planar imaging; dual-source parallel radiofrequency; axial scan; phase encoding in a back and forth direction; TR9000ms; TE85ms; TI260ms; FOV18cm X18cm; dense matrix 75X 72; slice thickness 3mm; slice interval 0mm; number of slices 60; echo train length 41; acceleration factor 2; b value 800s/mm (since we did not quantify the ADC value, only one b value was set up to reduce the scan time). MPGs were applied in the back and forth directions. The number of excitation was 12 and the acquisition time was 234s. For coronary or sagittal views, 3D MIP DWIBS images were reconstructed. Orientation was performed along the long axis of the affected nerve. T1WI parameters were as follows: TR/TE 550-600/20 ms; slice thickness 3-6mm; slice interval 0.3-0.5mm FOV 12-18 cm (four limbs, knee joints and calves) or 35-40cm (vagus nerve); acceleration factor 1.4-2; number of excitations 1-3. Except for the following parameters, T2WI and T2WI-SPAIR parameters were the same as the T1WI parameters: TR/TE 3000-5000/80-120ms.

Postprocessing

Postprocessing was done using Philips EWS workstation. One radiologist who was skilled in operations on the workstation undertook the 3D volume rendering of the raw axial images, as described in section 1. Fat-suppressed T2WI images are the most commonly used in clinic. On these images, peripheral nerves are shown as isointense signals or slightly hyperintense signals compared with the adjacent normal muscles. Spectral attenuated inversion recovery (SPAIR) fat suppression technique is usually used for brain imaging because of its high SNR. Recent studies have shown that 3D high-resolution DW MR sequence based on SSFP technique (3DDW-SSFP) is able to differentiate between the nerve and its accompanying vessel, which is otherwise difficult with the conventional fat-suppressed T2WI sequences. However, DDW-SSFP has the defects of long imaging time and sensitivity to motion artifacts. Besides, some normal tissues such as lymph nodes, vessels and fluid in articular cavity are often shown as hyperintense signals. On DWIBS blood vessels are shown as discontinuous hyperintense strip-like signals, lymph nodes as nodular hyperintense signals, and fluid as patchy signals. In contrast, nerves are usually shown as continuous uniformly hyperintense signals and are easily differentiated from the other tissues. In postprocessing, the interference signals irrelevant to the nerves were removed or subjected to 3D rotation and separated, so as to make the nerves more clearly visualized. Among 9 volunteers who received examination of the ophthalmic nerve, distal ocular vessels were closely associated with the orientation of the facial nerve in 2 cases (22%). As a result, the facial nerve was hardly discriminated from the vessels and not clearly visualized.

Examination results of the case group

The case group had 14 patients, including 5 patients with neurolemmoma, 1 patient with neurofibroma of the left ulnar nerve , 3 patients with neurofibromatosis, 1 patient with aggressive fibromatosis, 3 patients with nerve torsion and 1 patient with brain nerve injury. Two radiologists gave consistent scores for the relationship between the nerves and lesions on unilateral MPGs DWIBS and conventional T2WI-SPAIR sequences (the value=1). Except for 2 cases who were scored 1 on unilateral MPGs DWIBS sequences, all of the remaining cases were scored 3. On conventional T2WI-SPAIR sequences, only 7 cases were scored 3, and the remaining cases were scored 1 or 2. See Table 3. Unilateral MPGs DWIBS outperformed T2WI-SPAIR in visualizing neuropathy or the relationship between extraneural lesions and nerves ($Z=-2.607$; $P<0.05$). DWIBS can more accurately determine the scope of neuropathy and provide a more intuitive view of the lesions than T2WI-SPA1R. In 5 patients with neurolemmoma and 1 patient with neurofibroma of the left ulnar nerve, all tumors were presented as quasi-circular. The tumors and the nerves from which the tumors originated could be clearly visualized from DWIBS. For two patients with neurolemmoma that originated from above the ankle joint distal the eye, the relationship between the nerves and the lesions could be hardly differentiated on T2WI-SPAIR images. Quasi-circular neurolemmoma and neurofibroma were hardly differentiated on DWIBS and conventional sequences.

Subjective scoring of image quality

Two radiologists (having 20 and 10 years of experience in neuroradiology research, respectively) undertook the assessment of 3D DWIBS images for all healthy volunteers in an independent and random manner. Scoring was done based on the visualization of the full course of the nerves and the intensity of nerve signals on

a four-point scale. The scoring criteria were as follows: (1) 1: full course of the nerves was not fully shown; (2) 2: full course of the nerves was fully shown with moderate signal intensity; (3) 3: full course of the nerves was fully shown with fairly good signal intensity; (4) 4: full course of the nerves was fully shown with high signal intensity and high contrast with the surrounding tissues. Nerves in different positions were assessed based on the 3D DWIBS images. For the case group, two radiologists (having 20 and 10 years of experience in neuroradiology research, respectively) assessed the neuropathy and the relationship between the extraneural lesion and nerve on DWIBS and T2WI-SPAIR images in an independent and random manner. The assessment was done separately on the DWIBS and T2WI-SPAIR images. Scoring was performed on a three-point scale: (1) 1: neuropathy or the relationship between the lesion and the nerve was not visualized; (2) 2: the lesions might have been visualized, or only part of the lesions in those with multiple lesions were visualized; (3) 3: the lesions were clearly visualized. Pathological examination or surgical findings were taken as the gold standard. Pathological examination was performed by percutaneous puncture for 3 cases with neurofibromatosis, while the remaining 11 cases received surgery.

Table 1. Quality of DW-MRN sequences with MPGs applied in unilateral back-forth direction, unilateral left-to-right direction, three directions and six directions

	Unilateral back-forth direction	*Unilateral left-to-right direction*	*Three directions*	*Six directions*
Mean SNR	4.109 ±0.527	4.311 ±0.822	3.429 ±0.495	3.300 ±0.469
Mean CNR	0.604 ±0.042	0.606 ±0.133	0.543 ±0.052	0.529 ±0.054
Scores given by radiologist A	3.714 ±0.561	3.762 ±0.436	2.619 ±0.590	2.048 ±0.590
Scores given by radiologist B	3.667 ±0.577	3.714 ±0.463	2.571±	1.714 ±0.463

Statistical analysis

Statistical analyses were performed using SPSS software (version 17; SPSS, Chicago, 111). Interrater reliability was estimated by Cohen's Kappa statistic. The scores on DWIBS and T2WI-SPAIR images in the case group were compared by using Mann-Whitney U test. The significance level was set as a =0. 05. P<0.05 indicated significant difference.

Table 2. Scoring of DW-MRN sequences by two radiologists

	Unilateral back-forth direction	Unilateral left-to-right direction	Three directions	Six directions
1 point	0(0)	0(0)	0(0)	3(6)
2 points	1(1)	0(0)	9(9)	14(15)
3 points	4(5)	5(6)	11(12)	4(0)
4 points	16(15)	16(15)	1(0)	0(0)
Total	21(21)	21(21)	21(21)	21(21)

(Note: The number before the parenthesis is the rank count given by radiologist A for each patient; the number after the parenthesis is the rank count given by radiologist A for each patient)

Table 3. Comparison of nerve visualization rates

	STIR/longTE	*STIE-EPI DWI*	χ^2	*P*
Nerve root	37/64(0.578)	60/64(0.938)	18.983	<0.05
Ganglion	28/64(0.438)	57/64(0.891)	33.072	<0.05
Superior cranial nerves	52/64(0.813)	56/64(0.875)	0.502	>0.05
Inferior cranial nerves	44/64(0.688)	50/64(0.781)	1.135	>0.05

The above table shows the numbers of brain nerve roots, ganglia, superior cranial nerves and inferior cranial nerves visualized on different images and the comparison of the nerve visualization rate. The nerve visualization rate of STIR EP1DWI for brain nerve roots and ganglia was higher than that of STIR/long TE. But the two showed no significant difference in the visualization of superior cranial nerves and inferior cranial nerves.

Results

Unilateral MPGs DWIBS provided 3D stereoscopic views of major brain nerves, including olfactory nerve, brachial plexus, trigeminal nerve, facial nerve and glossopharyngeal nerve. For these nerves, radiologist A gave the scores of 3.79±0.43, 3.81±0.51, 3.43±0.81, 4±0 and 2.56±1.13, respectively; radiologist B gave the scores of 3.86±0.36, 3.86±0.48, 3.38±0.74, and 4.67±1.12, respectively. There was a high interrater reliability (k=0.766), and the average scores of the nerves were 3.61±0.75 and 3.64±0.71, respectively (see Table 2). The signal intensity was the lowest when using the parallel acquisition technique. When MPGs were applied to DWIBS unilaterally in the back-forth direction, whole-body brain nerves could be clearly visualized. DW-MRW was fit for extensive thin slab scan within a short period, and the 3D MIP-reconstructed images had high SNR and contrast. On DWIBS, tissues with long T2 or limited diffusion were also shown as hyperintense signals besides the nerves. Other studies have

indicated that SUSHI technique can inhibit the signals of the lymph nodes and fluid in the articular cavity. However, the inhibitory effect on blood vessels is poor and this technique has not been investigated in clinical cases. We applied DWIBS in brain imaging, and the scans were not influenced by factors related to high field strength, such as heterogenous main magnetic field, non-uniform radiofrequency field and magnetic susceptibility. This was mainly due to the use of parallel dual-source parallel radiofrequency, shimming operation, parallel acquisition technique, STIR fat suppression and phase array coil. Unilateral MPGs were also conducive to reducing the effect of geometric distortion in EPI images.

Conclusion

To conclude, unilateral MPGs DWIBS applied to brain neurography provides a clear 3D stereoscopic view of the major brain nerves, including olfactory nerve, brachial plexus, trigeminal nerve, facial nerve and glossopharyngeal nerve. There are three core principles of DWIBS for the imaging of peripheral nerves; (1) DWIBS consists of STIR fat suppression; (2) DWIBS suppresses the signals of surrounding muscles by DWI with a high b value. Nerves usually have longer transverse relaxation time (T2) and diffusion anisotropy. As a result, hyperintense water molecules have a higher diffusion speed along the orientation of the nerve fiber bundle. However, the diffusion perpendicular to the orientation of the nerve fiber bundle is restricted. For this reason, the signal intensity of nerves is related to the direction of MPGs applied. When MPGs are applied perpendicularly to the orientation of the nerve fiber, the signal intensity of the nerve is the highest. Thus, we recorded the conventional fat-suppressed T2WI images, while 3D MIP DWIBS images were reconstructed for coronal or sagittal view. Then orientation was performed according to the long axis of the affected nerve. Although narrow MPGs DWIBS can clearly visualize peripheral nerves and the lesions, background body signal suppression may be sometimes excessive and the specificity is lacking in the showing of lesions. To compensate for this defect, DW-MR is usually used in combination with conventional MR sequences.

References

Chhabra A, Andreisek G, Soldatos T, Wang KC, Flammang AJ, Belzberg AJ, Carrino JA. MR neurography: past, present, and future. American Journal of Roentgenology 2011; 197(3):583-91.

Chhabra A, Lee PP, Bizzell C, Soldatos T. 3 Tesla MR neurography-technique, interpretation, and pitfalls. Skeletal Radiology 2011; 40(10): 1249-60.

Dong Y, Wu CS, Lv QH, Li HK, Guo HM. Study of CO2 fluid density calculation model based on grayscale image, International Journal of Heat and Technology 2015; 33(1): 161-166.

Jambawalikar S, Baum J, Button T, Li H, Geronimo V. Diffusion tensor imaging of peripheral nerves. Skeletal Radiology 2010; 39(11): 1073-79.

Koh DM, Collins DJ, Orton MR. lntravoxel incoherent motion in body diffusion-weighted MRI: reality and challenges. American Journal of Roentgenology 2011;196(6):1351-61.

Kwee TC, Takahara T, Ochiai R, Nievelstein RA, Luijten PR. Diffusion-weighted whole-body imaging with background body signal suppression (DWIBS): features and potential applications in oncology. European Radiology 2008; 18(9): 1937-52.

Tagliafico A, Succio G, Neumaier CE, Serafini G, Ghidara M, Calabrese M, Martinoli C. MR imaging of the brachial plexus: comparison between 1.5-T and 3-T MR imaging: preliminary experience. Skeletal Radiology 2011; 40(6): 717-24.

Takahara T, Imai Y, Yamashita T, Yasuda S, Nasu S, Van Cauteren M. Diffusion weighted whole body imaging with background body signal suppression (DWIBS): technical improvement using free breathing, STIR and high resolution 3D display. Matrix 2004; 22(4): 275-282.

Tang L, Chen MJ. Image denoising method using the gradient matching pursuit, Mathematical Modelling of Engineering Problems 2016; 3(2): 53-56.

Vargas MI, Viallon M, Nguyen D, Beaulieu JY, Delavelle J, Becker M. New approaches in imaging of the brachial plexus. European Journal of Radiology 2010;74(2):403-10.

Willinek WA, Schild HH. Clinical advantages of 3.0 T MRI over 1.5 T. European Journal of Radiology 2008;65(1):2-14.

Yang E, Nucifora PG, Melhem ER. Diffusion MR imaging: basic principles. Neuroimaging Clinics 2011; 21(1):1-25.

Zhou YX, Kumaravel M, Patel VS, Sheikh KA, Narayana PA. Diffusion tensor imaging of forearm nerves in humans. Journal of Magnetic Resonance Imaging 2012;36(4): 920-27.