Performance Evaluation of a Rapid Three Dimensional Diffusion MRI

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ABSTRACT

MRI, particularly diffusion weighted imaging (DWI), plays vital roles in detection of the acute brain infarction[1-4] and others metabolic changes of biological tissues. In general, every molecule in biological tissues may diffuse and move randomly in three-dimensional space. However, in clinical diagnosis, only 2D-DWI is used. The authors have developed a new method for rapid three-dimensional DWI (3D-DWI). In this method, by refocusing of the magnetized spin with the applied gradient field, direction of which is opposite to phase encoding field. Magnetized spin of ^{1}H is kept under the SSFP (steady state free precession)[5-6]. Under SSFP, in addition of FID, spin echo and stimulated echo are also generated, so the acquired signal is increased. The signal intensity is increased depending on flip angle (FA) of magnetized spin. This phenomenon is confirmed by human brain and phantom studies. The performance of this method is quantitatively analyzed by using both of conventional spin echo DWI and 3D-DWI. From experimental results, three dimensional diffusion weighted images are obtained correctly for liquid phantoms (water, acetone and oil), diffusion coefficient is enhanced in each image. Therefore, this method will provide useful information for clinical diagnosis.

Keywords: *Diffusion weighted MRI, Three-dimensional imaging, SSFP.*

1.INTRODUCTION

The two-dimensional diffusion weighted image (2D-DWI) is actively using in clinical diagnosis. However, protons in biological tissues may diffuse and move randomly in three-dimensional space. It is difficult to analyze three dimensional diffusion movements and tissue structures by 2D-DWI. Therefore, it is needed to develop 3D-DWI methods. Characteristics of the proposed method in the image of phantom and human brain are quantitatively analyzed, and possibility of its application to clinical diagnosis is discussed.

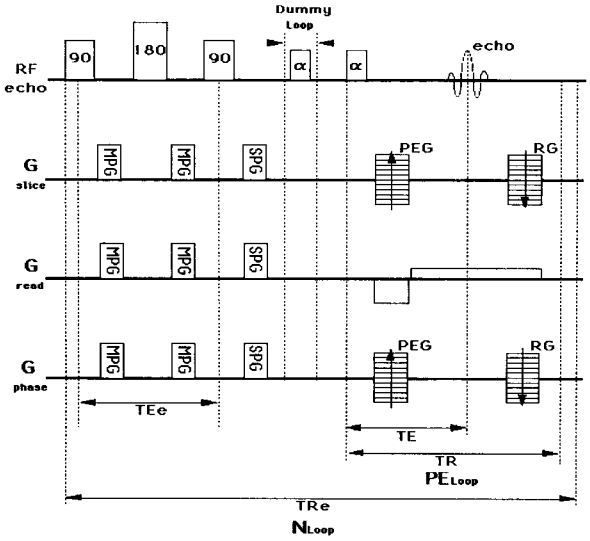
2. METHODS

Two intense gradient pulses (motion probing gradient; MPG) with a short duration are used in every diffusion sequences, and they are separated by a variable time interval named big-delta[7]. The echo attenuation is depending on the diffusion coefficient. Figure 1 shows the proposed 3D-DWI sequence. The acquired signal relevant to diffusion phenomenon is enhanced by a part of the sequence "90°RF → MPG → 180°RF → MPG → 90°RF". This enhancement is caused by phase differences of diffused magnetic moments. The spoiler gradient (SPG) in each direction as shown in the figure can eliminate the horizontal magnetization. The dummy loop performs "steady state free precession (SSFP)" for the vertical magnetization. And then the magnetic moment is imaged under SSFP by refocusing gradient (RG). The signal intensity is increased with appropriate flip angle (FA). Phantom and Brain images are acquired.

3. RESULTS AND DISCUSSION

Figure 2 shows the intensity of SSFP and Non-SSFP sequence with different flip angle (FA). As for the SSFP sequence, signal intensity increases with FA up to 63°. Under SSFP, in addition to FID, spin echo and s timulated echo are also generated, so higher intensity signal is observed compared with non-SSFP sequence.

Figure 3 shows 2D brain images (axial view) acquired by the proposed method in SSFP (a) and non-SSFP (b) respectively. For evaluation of the effects of SSFP in the method, MPG was not applied in each image acquisition. So, these images were enhanced just like T2 weighted images. These images were obtained with the TEe of 120msec, TRe of 2500msec, which led to acquisition time of 5.21 minutes for a 256 by 256 by 64 voxels. The maximum image intensity of each ROI was given at FA of 63 in SSFP and 10 degrees in non-SSFP, and the relative intensities in arbitr ary scale were 66 for gray matter (GM), 78 for white matter (WM) and 130 for CSF in SSFP, and 34 (GM), 51 (WM) and 7 (CSF) in non-SSFP, respectively.



MPG: Motion Probing Gradient
SPG: Spoiler Gradient
PEG: Phase Encoding Gradient
RG: Refocusing Gradient
TRe: Effective Repetition Time
TEe: Effective Echo Time
TR: Repetition Time of PE loop
TE: Echo Time of PE loop
PE_{Loop}: Phase Encoding Loop
N_{Loop}: Acquisition Loop

Fig. 1 A Proposed 3D Diffusion Imaging Sequence. Diffusion-related attenuation of the echosign al is obtained by two MPGs. This echo signal is acquired in each PE loop under SSFP.

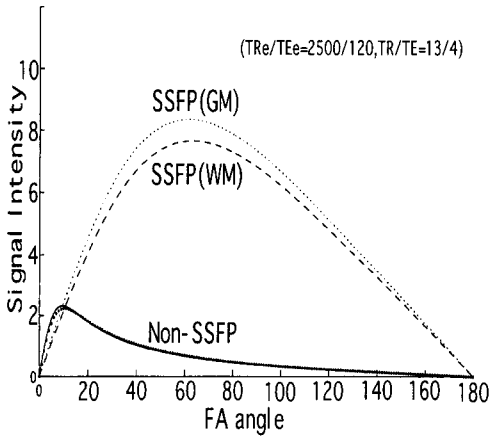


Fig. 2 The intensity of SSFP and non-SSFP sequence with different flip angle (FA)

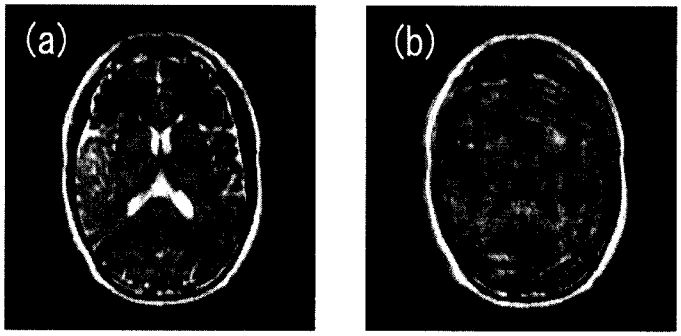


Fig. 3 T2 weighted brain image by the pro-posed method with FA=60° (a), and Non-SSFP method with FA=60° (b), respectively. (TRe2500msec, TEe120msec, TR13msec TE4msec)

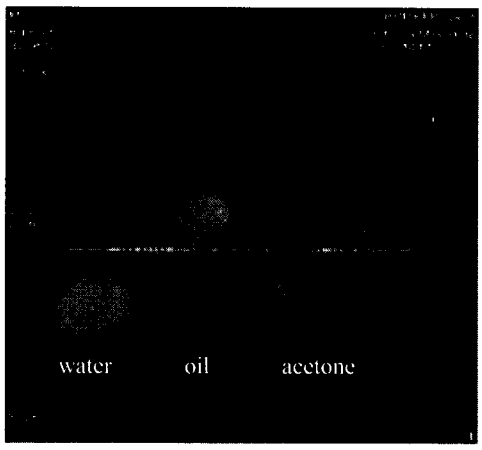


Fig. 4 3-D Diffusion weighted images of phantoms (water, oil, acetone)

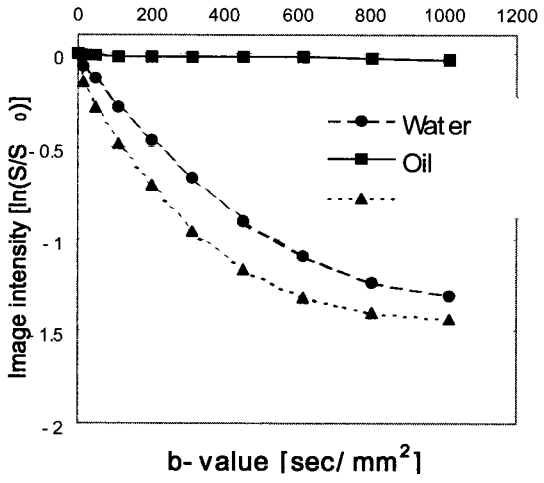


Fig. 5 The image intensity (mean value) v . s the MPG strength for phantoms of water, oil and acet one

Figure 4 shows 3D diffusion weighted image of phantoms (water, oil and acetone). This image was obtained with TEe of 30.1msec and TRe of 2000msec, which led to acquisition time of 6.5 minutes for a 128 by 128 by 128 voxels. Figure 5 shows the image intensity of the phantoms with different b-values. A molecule of water and acetone is quickly diffused compared with oil. The water and acetone image intensity have decreased greatly. The effect of the diffusion phenomenon on the image was confirmed in the proposed sequence.
As the proposed sequence as well as conventional sequence is very sensitive to the movement of the biological tissues, the navigator echo or other technique for motion compensation will be needed.

4. CONCLUSIONS

A new three-dimensional diffusion weighted imaging (3D-DWI) is proposed and discussed. From the results of phantom experiments and brain studies, the 3D diffusion weighted image was obtained. It was possible to keep the magnetic moment in the state of SSFP. The image intensity was found to be increased in SSFP. This method will provide useful information for clinical diagnosis.

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