The Comparison of Effects of Susceptibility Artifacts and Long Echo Time (TE) in Diffusion MRI by Single-Shot Echo-Planar Imaging and Readout-Segmented Echo-Planar Imaging at Prasat Neurological Institute

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บทคัดย่อ: เปรียบเทียบผลของรอยรบกวนชนิด Susceptibility และ Echo-Time (TE) ยาว ในการตรวจ Diffusion MRI โดยเทคนิค Single-Shot Echo-Planar Imaging และเทคนิค Readout-Segmented Echo-Planar Imaging ของสถาบันประสาทวิทยา

สมศักดิ์ จรรยาวัติวงศ์ วท.ม.
กลุ่มงานประสาทรังสีวิทยา สถาบันประสาทวิทยา แขวงทุ่งพญาไท เขตราชเทวี กรุงเทพมหานคร 10400

การวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบผลของรอยรบกวน (artifact) ชนิด susceptibility และผลของ echo time (TE) ที่ยาวในการตรวจ diffusion weighted imaging (DWI) ระหว่างเทคนิค single-shot echo-planar imaging (SS-EPI) และเทคนิค readout-segmented echo-planar imaging (RS-EPI) ในเครื่องสร้างภาพด้วยสนามแม่เหล็กไฟฟ้า (MRI) ขนาด 3 เทสลาของสถาบันประสาทวิทยา โดยศึกษาย้อนหลัง (retrospective) ในผู้ป่วยที่มาตรวจ MRI ด้วยเทคนิค SS-EPI DWI และ RS-EPI DWI กลุ่มละ 38 คน ใช้ head coil ชนิด 32 ช่องสัญญาณ โดยใช้ diffusion trace image ในการประเมินรอยรบกวนชนิด susceptibility และผลของ TE ยาว และใช้ภาพ T2-weighted ซึ่งแสดงกายวิภาคได้ใกล้เคียงของจริง ในการเปรียบเทียบความผิดเพี้ยนกับภาพ EPI-DWI การศึกษานี้ได้ทำการเปรียบเทียบทั้งสองเทคนิคในห้าหัวข้อคือ จำนวนภาพที่มีสัญญาณเพิ่มขึ้น การประเมินคุณภาพจากความรุนแรงของการเกิดรอยรบกวนชนิด susceptibility (quality evaluation) การประเมินความผิดเพี้ยนด้านระยะทาง (quantitative evaluation) การเปรียบเทียบผลของรอยรบกวนที่เกิดจากโลหะ และผลต่อ SNR (เกิดจาก TE ยาว) ผลการศึกษาพบว่าค่าเฉลี่ยของจำนวนภาพที่มีสัญญาณเพิ่มขึ้นในเทคนิค SS-EPI เมื่อเปรียบเทียบกับเทคนิค RS-EPI เท่ากับ 5.92 (S.D.=1.09) และ 2.73 (S.D.= 1.13) ตามลำดับ (P<0.001) ผลด้านคุณภาพพบว่าเทคนิค SS-EPI ผิดเพี้ยนมากกว่าเทคนิค RS-EPI 3 ระดับคุณภาพสเกล (image quality scale) P<0.001 ความผิดเพี้ยนด้านระยะทางเปรียบเทียบระหว่างเทคนิค SS-EPI และ RS-EPI โดยวัดระยะบริเวณ cerebellum 1 ตำแหน่ง และที่ระดับ lateral ventricles ทั้งในแนว phase encoding และ frequency encoding โดยเปรียบเทียบกับภาพ T2-weighted ของแต่ละเทคนิคในระดับเดียวกัน มีค่าเท่ากับ 2.49 มิลลิเมตร/1.00 มิลลิเมตร, 6.03 มิลลิเมตร/2.13 มิลลิเมตร และ 1.27 มิลลิเมตร/0.89 มิลลิเมตร ตามลำดับ (P<0.001) ผลของรอยรบกวนที่เกิดจากสาเหตุผู้ป่วยมีโลหะในเทคนิค SS-EPI พบว่าร้อยละ 87.5 อยู่ในระดับค่อนข้างมาก (ระดับสเกลที่ 3-4) ขณะที่พบเพียงร้อยละ 30 ในเทคนิค RS-EPI (P=0.031) และผลต่อ SNR พบว่าค่าเฉลี่ยของ SNR บริเวณ cerebellum ของเทคนิค SS-EPI และ RS-EPI มีค่าเท่ากับ 161.14 (S.D.=29.29) และ 150.85 (S.D.=51.21) ตามลำดับ (P= 0.287) ค่าเฉลี่ยของ SNR ที่ระดับ lateral ventricles ของเทคนิค SS-EPI และ RS-EPI มีค่าเท่ากับ 141.63 (S.D.=27.07) และ 123.04 (S.D.=42.46) ตามลำดับ (P= 0.026) และอัตราส่วนของ SNR ระหว่างเทคนิค RS-EPI และ SS-EPI บริเวณ cerebellum และที่ระดับ lateral ventricles มีค่าเท่ากับ 0.94 และ 0.87 ตามลำดับ (P<0.05) จากผลการศึกษานี้พบว่าการตรวจ DWI ในเทคนิค RS-EPI มีรอยรบกวนชนิด susceptibility น้อยกว่าเทคนิค SS-EPI โดยเฉพาะในบริเวณรอยต่อของเนื้อเยื่อที่มีค่า magnetic susceptibility แตกต่างกัน ผู้ป่วยที่มีวัตถุประเภทโลหะที่เกิดจากการผ่าตัดควรได้รับการตรวจ DWI โดยเทคนิค RS-EPI เพื่อลดรอยรบกวนประเภท susceptibility ที่ไม่พึงประสงค์ และเพิ่มความถูกต้องในการวินิจฉัย

คำสำคัญ: เทคนิคภาพเน้นน้ำหนักดิฟฟิวชั่น รอยรบกวนชนิด susceptibility เทคนิค echo-planar imaging ชนิดอ่านค่าเป็นส่วนๆ เทคนิค echo-planar imaging ชนิดยิงครั้งเดียว

Abstract

The aim of this study was to compare susceptibility artifact and effect of long echo time (TE) between single-shot echo-planar imaging (SS-EPI) and readout-segmented echo- planar imaging (RS-EPI) diffusion weighted imaging (DWI) in 3 Tesla MRI machine at Prasat Neurological Institute. This was a retrospective study of 38 patients who underwent SS-EPI and RS-EPI DWI in each group. All scans were performed on a 3T MR scanner using 32 channel head coil. Susceptibility artifacts (geometric distortion, hyper-intensity signal and signal loss) and effect of long TE (will result in signal to noise ratio; SNR) were evaluated on diffusion trace images. The anatomic information of T2- weighted images was used to compare distortion with EPI DWI images. The study was done in five topics: number of slices that contain hyper-intensity signal, the severity of susceptibility artifacts (evaluated in image quality scale), geometric distortion (quantitative evaluation), comparing the effect of metal-induced artifacts between SS-EPI and RS-EPI DWI and comparing SNR between SS-EPI and RS-EPI DWI. The results showed that mean (SD) of slices containing hyper-intensity signal in SS-EPI is 5.92 (1.09) and in RS-EPI DWI is 2.73 (1.13) (P<0.001). The susceptibility artifacts in SS-EPI image was prominent compared with RS-EPI DWI (different in 3 levels of image quality scales). The different distance between SS-EPI and RS-EPI DWI at the level of cerebellar hemispheres, the level of lateral ventricles in phase direction and the level of lateral ventricles in frequency direction with its own T2-weighted images at the same position were 2.49 mm/1.00 mm, 6.03 mm/ 2.13 mm, and 1.27 mm/0.89 mm, respectively (P<0.001). The effect of metal-induced artifacts is quite severe (level 3-4) to 87.5% in SS-EPI DWI, while only 30% found in the RS-EPI DWI (P=0.031). Mean (SD) of SNR at the cerebellum in SS-EPI and RS-EPI were 161.14 (29.29) and 150.85 (51.21), respectively (P=0.287). Mean (SD) of SNR at the level of lateral ventricles in SS-EPI and RS-EPI were 141.63 (27.07) and 123.04 (42.46), respectively (P= 0.026). The ratios of SNR between RS-EPI and SS-EPI DWI were 0.94 for the cerebellum and 0.87 for the level of lateral ventricles. This study shows that RS-EPI has less susceptibility artifacts (geometric distortion, hyper-intensity signal and signal loss) than SS-EPI in diffusion trace image, especially at the regions which have different magnetic susceptibilities that are juxtaposed or with patient who have metallic implants and devices. Patients who have pathology in these areas or have metallic implants or devices, should select RS-EPI sequence to perform DWI.

Keywords: Diffusion Weighted Imaging (DWI), Susceptibility artifact, Readout-Segmented Echo-Planar Imaging (RS-EPI), Single-shot Echo-Planar Imaging (SS-EPI)

Introduction

Current physical examination, magnetic resonance imaging (MRI) machine plays an important role in the diagnosis of neurological lesions, especially as it can be shown clearly. There is a technical examination of several types that help diagnose diseases such as the vessels (Magnetic Resonance Angiography, MRA), the bio-chemically substances (Magnetic resonance spectroscopy, MRS), to examine the movement of water (MR Diffusion or Diffusion Weighted Imaging, DWI). The application of DWI in clinical studies are providing new ways to study problems in oncology[1], epilepsy, white matter disorders and infectious diseases, particularly in the evaluation of acute stroke[2-3]. DWI is typically obtained by measuring the signal loss after the addition of a pair of rectangular diffusion sensitizing gradients (equal in strength and opposite in polarity and effect) to either side of the 180° pulse of a spin echo sequence[4-5] (fig 1). Most commonly, DWI is performed using single-shot spin-echo planar imaging (SS-EPI) technique which provides reliable clinical images free from motion induced artifact. Using a single spin-echo RF excitation, the entire k-space is filled by rapid positive/negative oscillation in single readout (fig 2). While fast and relatively motion-insensitive, it is likely to suffer from susceptibility artifacts at tissue interfaces, especially at higher field strengths. Spatial resolution is limited by the T2* decay during the long readout time. Magnetic susceptibility corresponds to the internal magnetization of a tissue resulting from the inter actions with an external magnetic field. When two tissues with different magnetic susceptibility are close together, it causes local distortion in the magnetic field. For in vivo imaging, interfaces between water containing tissue-air and soft tissue-bone have most pronounced susceptibility differences. However, air has much greater impact on the local field than bone[6].

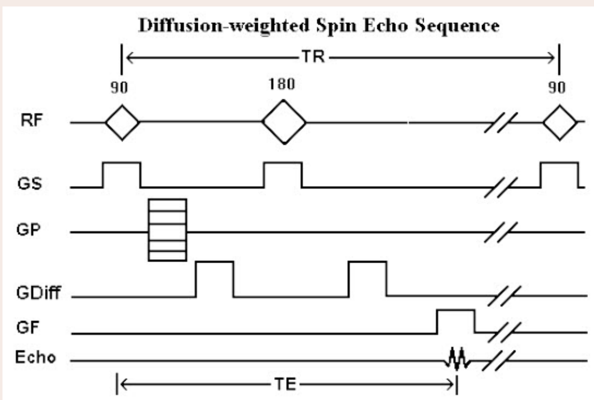

Fig 1 **Basic DWI pulse sequence diagram**

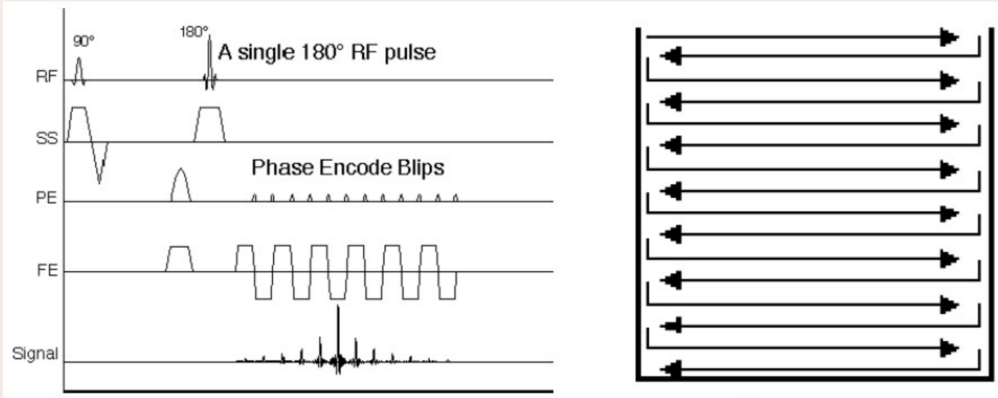

Fig 2 Show the pulse diagram of SS-EPI (left) and the trajectory through k-space during one TR (right).

These static field inhomogeneities (T2*) create dephasing and frequency shift of nearby spins. This results in significant magnetic susceptibility artifacts, to which EPI-based sequences are prone[7]. Geometric distortion, hyper-intense signals and signal loss are frequent, sometimes making DWI difficult to interpret. While geometric distortion artifact is caused by the in-plane local gradient, signal loss is caused by the through plane local gradient. Another undesirable effect of the long sampling in SS-EPI is that it will impose a relatively long echo time (TE)[8]. Long TE, due to a combination of the diffusion-encoding gradients and the long data sampling interval, results in low SNR data. Susceptibility artifacts can be reduced by sampling the k-space faster, which decreases the accumulation of the phase errors. The benefits of faster sampling are not only reducing susceptibility distortion but also enabling shorter TE. Faster acquisition can be achieved by reducing the echo spacing, which is defined as the total time between the applications of two phases-encode blips. Echo spacing can be reduced in several ways. One of them is to use multi-shot techniques. Readout-segmented echo-planar imaging (RS-EPI) has been suggested as an alternative approach to multi-shot EPI for high resolution DWI with reduced susceptibility artifact[9]. The pulse timing diagram and k-space traversal of the RS-EPI is shown in Figure 3. The first spin echo in RS-EPI, k-space is filled with a series of concatenated segments in the readout direction. In this manner, each shot was used to sample a different segment in the k_x direction. The smaller readout gradient moment associated with the reduction of k_x coverage, allows a substantially shorter echo-spacing than with SS-EPI, significantly reducing the effect of susceptibility artifact and shorter TE (make higher SNR). Motion correction is performed using a 2D navigator (the second echo in RS-EPI) to correct for motion-induced, non linear phase errors.

Therefore, this study describes the differences of the two DWI techniques in susceptibility artifact and effect of long TE in 3 Tesla MRI machine at Prasat Neurological Institute.

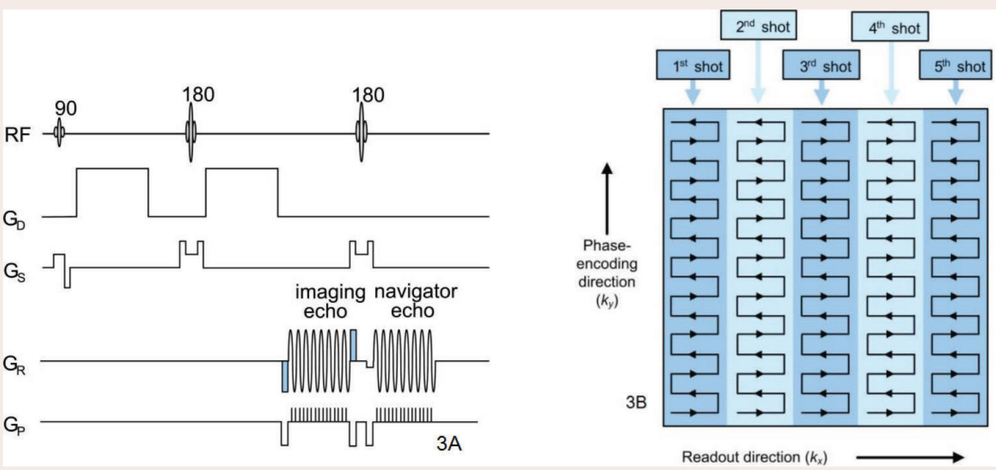

Fig 3 Show the pulse diagram of RS-EPI (3A) and the k-space trajectory (3B)

Materials and Methods

This study was approved by the institutional review board of Prasat Neurological Institute, and the informed consent was waived because of the retrospective nature of the study. The study consisted of 38 patients who underwent SS-EPI DWI (18 male and 20 female patients with an average age of 53.1 years) and RS-EPI DWI (17 male and 21 female patients with an average age of 47.4 years) in each technique. All scans were performed on a 3T MR scanner (Magnetom Skyra TIM; Siemens Medical Solution, Erlangen, Germany) using commercially 32 channel head coil in axial SS-EPI DWI, axial RS-EPI DWI and axial fat suppression T2- weighted turbo spin echo sequence. SS-EPI DWI images were acquired with the following parameters: parallel imaging using GRAPPA with acceleration factor of 2, FOV 220 mm, matrix 192x192, no phase partial Fourier factor, pixel size 1.1 mm x 1.1 mm, slices 24, slice thickness 5 mm, echo spacing 1.04 ms, TR 5,200 ms, TE 100 ms, one scan at b=0 s/mm^2 and three scans at b = 1,000 s/mm^2 in orthogonal direction, two averages and total measurement time 59 s. RS-EPI DWI images were acquired with the following parameters: parallel imaging using GRAPPA with acceleration factor of 2, FOV 220 mm, matrix 192x192, no phase partial Fourier factor, pixel size 1.1 mm x 1.1 mm, slices 24, slice thickness 5 mm, echo spacing 0.4 ms, TR 4200 ms, TE 78 ms, one scan at b=0 s/mm2 and three scans at b = 1000 s/mm^2 in orthogonal direction, one average, 5 readout segments per image and total measurement time 1 min 38 s. The anatomic information of T2- weighted images (used to compare distortion with EPI DWI images) were also acquired with the following parameters: non acceleration factor, FOV 210 mm, matrix 324x512, no phase partial Fourier factor, pixel size 0.4 mm x 0.4 mm, slices 24, slice thickness 5 mm, echo spacing 11.1 ms, TR 5,320 ms, TE 100 ms, one average and total measurement time 1 min 44 s. All images were reviewed through our institution's picture archiving and communication system.

Susceptibility artifacts (geometric distortion, hyper-intensity signal and signal loss) and effect of long TE (signal to noise ratio; SNR) were evaluated on diffusion trace images. Measurement of susceptibility artifacts in this study was divided into two types. One is an evaluation of image quality and the other is the distortion measurement in quantitative evaluation. This study was done in five topics.

1. Counting the number of slices that contain hyper-intensity signal: At the tissues interface region of EPI DWI not only shows distortion along the phase encoding direction (Antero-posterior), but also shows an increase in signal intensity caused by the overlap of distorted voxels[8].
2. Quality evaluation of susceptibility artifacts: Six image quality scale (Table 1) was evaluated to specify the severity of susceptibility artifacts at areas of interest (contours of skull base, parietal lobe, frontal lobe). Images quality of DWI is much worse if there is ghosting artifact involved.[4,10] In the ghosting artifact or Nyquist (N/2) artifact, image ghosts appear in half the field of view in the phase-encoding direction. These artifacts arise as a result of a zigzag data acquisition pattern in EPI sequence, in which the signal is sampled during both the positive and negative half of the frequency-encoding gradient.

Table 1 The image quality scales (0 – 5)

5	Perfect contour of image (compare to T2-weighted image)
4	good contour with hyper-intensity less than 5 slices
3	good contour with hyper-intensity more than 5 slices
2	distortion and has no ghost artifact with hyper-intensity less than 5 slices
1	distortion and has no ghost artifact with hyper-intensity more than 5 slices
0	significant distortion and has ghost artifact

3. Quantitative evaluation of geometric distortion: Quantitative evaluation of geometric distortion was performed at two levels; first position was measured in transverse direction at the level of cerebellar hemispheres (as much the distortion was found in this area) and second position was measured both phase and frequency direction at the level of lateral ventricles (as it was the greatest distance of the brain contour). Distortion was measured as the maximum distance in the transverse direction between brain borders on the diffusion trace images (b=1,000 sec/mm^2) and T2-weighted images (Fig 4). Both SS-EPI and RS-EPI DWI were compared with its own T2-weighted images.

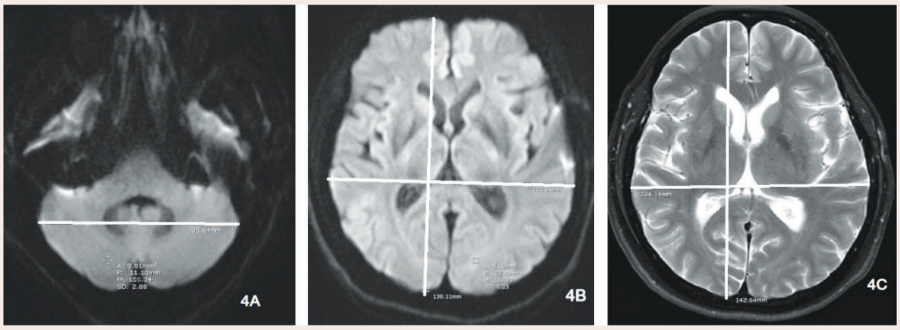

Fig 4 **Distortion was measured as the maximum distance in the transverse direction between brain borders on the diffusion trace image: b=1,000 sec/mm^2 (4A, 4B) and T2- weighted image (4C) at the level of cerebellar hemispheres and the level of lateral ventricles.**

4. The effect of metal-induced artifacts: Comparing the effect of metal-induced artifacts between SS-EPI and RS-EPI DWI on the diffusion trace images (b=1,000 sec/mm^2); near metal objects, the magnetic field variation can be very rapid, such that the magnetization within a single image voxel precesses at varying rates. The presence of metallic implants in MRI can cause substantial image artifacts, including signal loss, failure of fat suppression, geometric distortion and bright pile-up artifacts[11]. In this study, the effect of metal-induced artifacts were categorized into the strength levels as follows: 1 = low (no signal loss/no bright pile-up artifact/image distortion only 1 slice), 2 = moderate (no signal loss/light bright pile-up artifact/image distortion 2-3 slices), 3 = high (signal loss/ bright pile-up artifact/image distortion 4-5 slices) and 4 = very high (signal loss/ bright pile-up artifact/image distortion > 5 slices).

5. The effect of long TE: Comparing SNR between SS-EPI and RS-EPI DWI at the level of cerebellar hemispheres and the level of lateral ventricles on the diffusion trace images (b=1,000 s/mm^2); this study was just to compare SNR efficiency of RS-EPI and SS-EPI DWI from the signal intensity and standard deviation taken directly in ROIs located in brain tissues.

Image quality scales were analyzed with Fisher's exact test ($P < 0.001$). Distortion measurement (quantitative evaluation) and number of hyper-intensity signal were analyzed using a paired t test ($P < 0.05$). And the images caused by metal-induced artifacts were analyzed with Chi-square test ($P < 0.05$). Statistical analyses were performed by using software (SPSS, version 16.0).

Results

The mean (SD) of slices containing hyper-intensity signal in SS-EPI is 5.92 (1.09) (range, 3 to 9 slices) and in RS-EPI DWI is 2.73 (1.13) (range, 1 to 5 slices) with $P<0.001$. Figure 5 shows a comparison of the effect hyper-intensity signal between SS-EPI and RS-EPI in DWI.

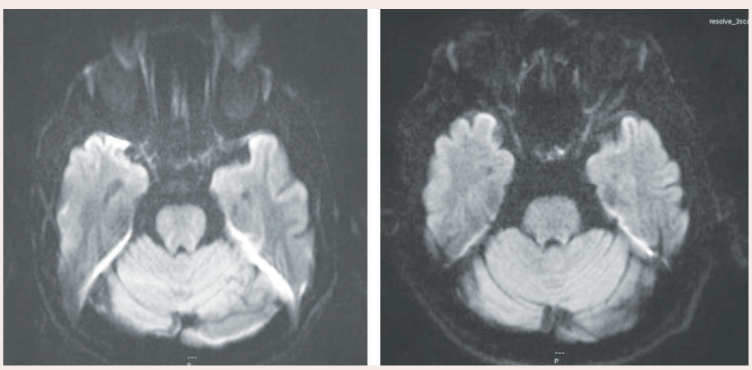

Fig 5 **Comparison of SS-EPI (left) and RS-EPI DWI (right). At temporal lobe of RS-EPI, it shows not only less image distortion in phase direction (Antero-posterior), but also shows a reduction in hyper-intensity signal.**

Table 2 The results of image quality scale in SS-EPI and RS-EPI DWI.

Image quality scale	SS-EPI DWI (numbers : % within group)	RS-EPI DWI (numbers : % within group)
4	0 (0%)	36 (94.7%)
3	0 (0%)	1 (2.6%)
2	2 (5.3%)	1 (2.6%)
1	25 (65.8%)	0 (0%)
0	11 (28.9%)	0 (0%)

The result of image quality is shown in Table 2. In SS-EPI DWI images, strong susceptibility artifacts can be observed as image distortions, ghost artifacts and hyper-intensity signal, approximately 95% are in the scale 0 to 1. On the other hand in RS-EPI DWI images, the same area shows a significant reduction in this susceptibility artifacts, approximately 95% are in the scale 4 ($P < 0.001$). The reduced distortion in RS-EPI DWI gave increased diagnostic confidence in cerebellum and temporal regions (Fig 5). The distances in transverse direction at the level of cerebellar hemispheres, level of lateral ventricles in both phase and frequency directions for SS-EPI DWI, RS-EPI DWI and T2- weighted images, are shown in table 3. It was found that the contour of RS-EPI DWI similar to T2-weighted image more than SS-EPI DWI. The different distance between SS-EPI and RS-EPI DWI in the level of cerebellar hemispheres, level of lateral ventricles in phase direction and level of lateral ventricles in frequency direction with its own

Table 3 Shows the distance of contours at interesting level of SS-EPI, RS-EPI DWI and T2-weighted image

Types of DWI	Distance at interesting areas	Mean (SD) distance (mm)	Different between its pair (mm)
SS - EPI DWI	Distance at cerebellum DWI	95.92 (4.33)	2.49
	Distance at cerebellum T2-weighed	98.41 (4.50)	
	Distance at level of lateral ventricles DWI (Phase)	143.74 (8.81)	6.03
	Distance at level of lateral ventricles T2-weighted (Phase)	149.76 (8.49)	
	Distance at level of lateral ventricles DWI (Freq)	131.47 (4.97)	1.27
	Distance at level of lateral ventricles T2-weighted (Freq)	132.73 (5.19)	
RS - EPI DWI	Distance at cerebellum DWI	99.79 (5.45)	1.00
	Distance at cerebellum T2-weighed	100.79 (5.35)	
	Distance at level of lateral ventricles DWI (Phase)	146.83 (8.65)	2.13
	Distance at level of lateral ventricles T2-weighted (Phase)	148.95 (8.87)	
	Distance at level of lateral ventricles DWI (Freq)	131.01 (4.89)	0.89
	Distance at level of lateral ventricles T2-weighted (Freq)	131.89 (4.59)	

T2 –weighted images at the same position were 2.49 mm / 1.00 mm, 6.03 mm / 2.13 mm, and 1.27 mm / 0.89 mm, respectively ($P<0.001$). In this study, 23.7% (18/76 cases) of the population was found to have the effect of metal-induced artifacts. The effect of metal-induced artifacts is quite severe (level 3-4) to 87.5% (7/8 cases) in SS-EPI DWI, while only 30% (3/10 case) found in the RS-EPI DWI; $P = 0.031$ (Table 4).

Table 4 The result of the effect of metal-induced artifacts scores of SS-EPI and RS-EPI DWI

Severity of metal-induced artifacts score	SS-EPI DWI	RS-EPI DWI
1 = Low	0 (0%)	1 (10%)
2 = moderate	1 (12.5%)	6 (60%)
3 = High	3 (37.5%)	3 (30%)
4 = Very high	4 (50.0%)	0 (0%)
Total	8 (100%)	10 (100%)

At Prasat Neurological Institute, after performing a craniotomy, bone flaps are typically fixed with wire, suture material, or small plates and screws while surgical staples are specialized staples used in surgery in place of sutures to close skin wounds. These metallic devices cause the most effective artifact in SS-EPI DWI when compared to RS-EPI DWI (Fig 6 and 7 showing the follow-up cases of the same patient underwent both SS-EPI and RS-EPI DWI at different times). This study was found that RS-EPI DWI can reduce the occurrence of the effect of metal-induced artifacts. The mean (SD) SNR at the level of cerebellar hemispheres between SS-EPI and RS-EPI DWI on the diffusion trace images (b=1000 s/mm^2) were 161.14 (29.29) and 150.85 (51.21), respectively (P=0.287). The mean (SD) SNR at the level of lateral ventricles between SS-EPI and RS-EPI DWI on the diffusion trace images (b=1000 s/mm^2) were 141.63 (27.07) and 123.04 (42.46), respectively (P=0.026). The SNR ratios between RS-EPI and SS-EPI DWI were 0.94 for the cerebellum and 0.87 for the level of lateral ventricles.

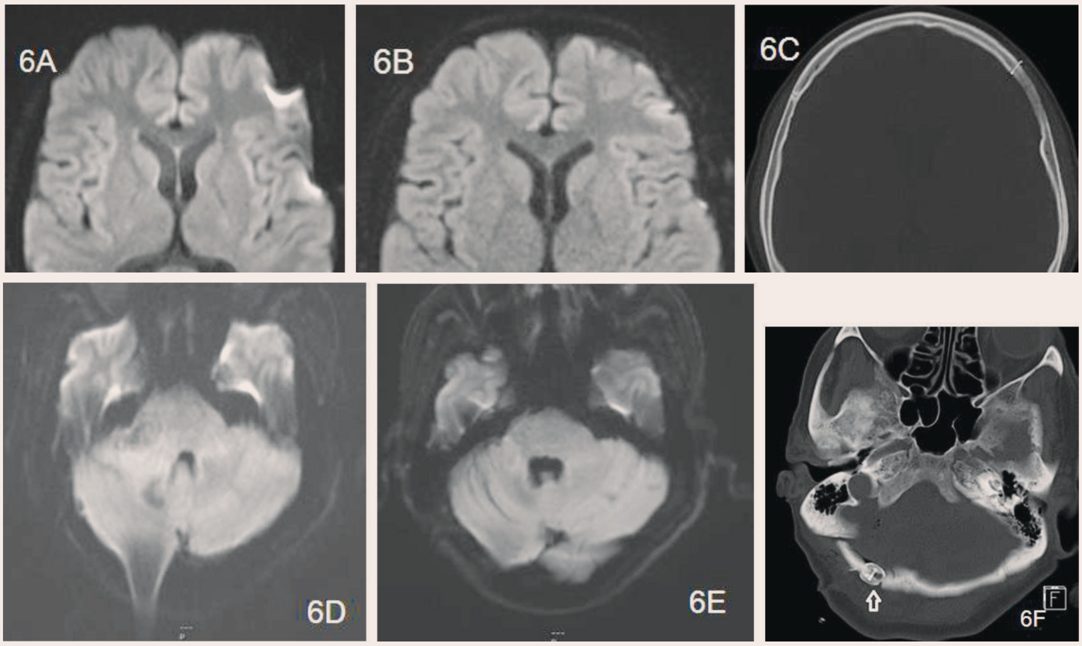

Fig 6 **Direct comparison of signal loss, bright pile-up artifact and image distortion: at the left frontal lobe between SS-EPI (6A) and RS-EPI (6B) with effect by metallic devices in CT (6C), at the right occipital lobe between SS-EPI (6D) and RS-EPI (6E) with effect by metallic devices in CT (6F).**

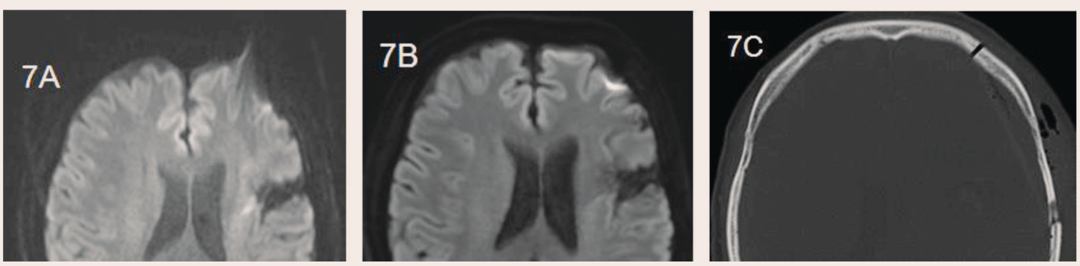

Fig 7 **Show the difference of image distortion between SS-EPI (7A) and RS-EPI (7B) after performing craniotomy without metallic devices (7C).**

Discussion

DWI is a good method for neurologic applications, it is the most sensitive method for detection of acute ischemia in vivo. In DWI sequence, SS-EPI is most commonly used as it very robust to motion artifacts and allow very short acquisition times. However in SS-EPI images, susceptibility artifacts are often severe, especially at 3T. While currently, there is alternative performing of DWI, RS-EPI which significantly reduces these artifacts by allowing a shorter echo-spacing (640 μsec compared to SS-EPI in this study) in the EPI echo-train with a series of concatenated segments in the readout direction as seen in Figure 1. This study shows that to use SS-EPI instead of RS-EPI caused increase number of slices that have hyper-intensity signal 116.84%. Figure 5-7 show that RS-EPI results qualitatively (the image quality) and quantitatively (distortion of contour compare to T2-weighted image) in significantly less susceptibility artifacts than SS-EPI in the diffusion trace images, especially at interfaces between tissues with has different magnetic susceptibility. The results of this experiment shows that the distortion in phase direction is greater than in frequency direction in both SS-EPI and RS-EPI DWI, but the differences value in SS-EPI is greater than RS-EPI. Figure 6 show a good example to compare the effect of metal-induced artifacts between the two techniques in the patients who have metallic implants and devices. In the RS-EPI DWI, it was found that 70% (7/10 cases) of metal-induced artifacts is in the low to moderate level (level 1-2) while only 12.5% (1/8 cases) was found in SS-EPI DWI. The SNR of RS-EPI DWI was slightly less than around 10% of that of SS-EPI DWI because they may not use the same average parameter. However, the overall quality of the images of RS-EPI was better than SS-EPI. The main disadvantage of the RS-EPI is that it requires longer overall scan times compared with SS-EPI (different time in this study = 39 sec), potentially in patient motion. To overcome effect of patient motion, a 2D navigator echo was used to detect the phase error which may cause increase the scan time. However, the increase in scan time compared to the benefits, would be worth for it.

Conclusion

Magnetic field inhomogeneities are a major source for susceptibility artifacts. Standard SS-EPI DWI is sensitive to susceptibility artifacts at 3T, even when parallel imaging techniques, such as GRAPPA, are used to reduce the effective echo spacing. A new multi-shot technique, RS-EPI for acquiring high quality DWI is a useful protocol to the reduction of susceptibility artifacts and shorten the echo time (higher SNR). Additionally, RS-EPI sequence may be particularly useful in cases where patients have metallic implants and devices. In present time, Prasat Neurological Institute uses the RS-EPI as a routine protocol in DWI.

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