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FULL PAPER

Radiofrequency artefacts in echoplanar imaging induced by two 1.5 T MR scanners in close proximity

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Objective: The purpose of this study was to assess radio frequency (RF) artefacts in echoplanar imaging (EPI) induced by two 1.5 T MR scanners in close proximity and to find an effective method to correct them.

Methods: Based on the intact shielding of rooms, experiments were performed by two MR scanners with similar centre frequencies. Phantom A (PA) was scanned in one scanner by EPI at different bandwidths (BW). Simultaneously, phantom B was scanned in a fixed sequence for scanning with the other scanner. RF artefact gaps of PA, scanning time and the image signal-noise ratio (SNR) were measured and recorded. Statistical analysis was performed with the repeated-measures analysis of variance test. Based on findings obtained from PA, three healthy volunteers were

studied at a conventional BW and a lower BW to observe the artefact variance.

Results: EPI RF artefacts were symmetrically situated in both sides of the image following the phase-encoding direction. The gap size of the artefact became larger and the SNR was significantly improved with a narrower BW. RF artefacts with a lower BW in volunteers presented the same characteristic as PA.

Conclusion: For EPI RF artefacts produced by two 1.5 T MR scanners with approximately similar centre frequencies, we can reduce BWs in a suitable range to minimize the effect on MRI.

Advances in knowledge: MR scanners with the same field strength installed in the same vicinity might produce RF artefacts in the sequence at larger BWs. Reducing BWs properly is effective to control the position of artefacts and improve the image quality.

Owing to the limited space and inappropriate planning, two 1.5 T MR scanners in our hospital were installed with their apertures facing each other at the same level. Subsequently, artefacts appeared in MR images when they were used at the same time. Artefacts that severely impaired the quality of MR images were a band or zipper of intensity perpendicular to the frequency-encoding direction. They frequently appeared in many conventional sequences, so that the scanning could not work. We and the engineers studied the characteristics of the artefacts and considered them radiofrequency (RF) artefacts. We tried our best to search for the interference source, but we could not be sure what instrument it came from. After recording and analysing artefacts, we found an apparent law. Only when two scanners were used at the same time did the RF artefacts appear in many sequences. After closing the RF coil of one scanner, RF artefacts disappeared from the images of the other. Therefore, we considered that these artefacts were produced from the interaction between two scanners.

Two MR scanners have the same field strength of 1.5 T and a similar approximate centre frequency (Avanto =

63.680982 MHz; Symphony = 63.685914 MHz). The difference of the centre frequencies between both scanners is 4932 Hz. As soon as half of the sampling rate of the sequence is >4932 Hz, RF of the opposite scanner will be received and fill in the k-space corresponding to the frequency range when both scanners are working simultaneously. Accordingly, the disciplinary RF artefacts appeared in the images. Based on the above-mentioned reasons, an MR engineer adjusted the centre frequency of one scanner from 63.680982 to 63.580982 MHz to increase the difference of centre frequencies to 96,094 Hz between both scanners. Therefore, RF artefacts disappeared in the conventional sequences. Nevertheless, RF artefacts remained in the sequences with a larger number of samples and bandwidth (BW). RF artefacts appeared in diffusion-weighted imaging (DWI) with echoplanar imaging (EPI), which was oriented at two parallel hyperintense signal bands crossing the image in the phase-encoding direction, and the image qualities were interfered without improvement. Although we could make further adjustment of the centre frequency, it would be at a high risk. Therefore, we adopted another method to optimize the parameter to eliminate the artefacts.

The objective of this article is to present a severe RF artefact in EPI DWI and to evaluate whether adjusting the BW in a suitable range can be helpful to eliminate or decrease the effect of RF artefact on MR images. For this purpose, the positions of the RF artefacts were recorded. Image quality, scanning time and the characteristics of RF artefacts were evaluated on a consecutive phantom in a scanner. Then, these results were applied *in vivo* to suggest a practical method for correcting RF artefacts of two 1.5 T MR scanners in close proximity.

Two 1.5-T MR scanners (MAGNETOM Avanto and MAGNETOM Symphony) operating at very similar centre frequencies were installed in close proximity ([Figure 1](#)). MR rooms were tested by experts of MR shielding in accordance with the standards (IEEE

The two water phantoms were placed in the centre of head coils by means of foam padding. They were driven into the magnets and imaged to demonstrate the results of different BWs on EPI RF artefacts. A time period of 3 min was allowed to elapse so that the fluid in the phantom settled before the images were taken. Phantom A (PA) was scanned with a conventional head DWI sequence with EPI technology and conventional BW was 1240 Hz Px⁻¹ (BW4) with a head matrix coil in the Avanto scanner. Transverse DWI sequences with parallel acquisition and fat suppression were acquired: repetition time (TR)/echo time (TE) = 3000/93 ms; field of view (FOV) = 230 mm²; matrix = 192 × 192; slice thickness = 5 mm; 0.5 mm slice spacing; $b_1 = 0$ s mm⁻²; and $b_2 = 1000$ s mm⁻². The routine sequence was applied to the anteroposterior phase-encoding direction. Sequentially, PA was scanned with the following five different BWs: BW1 = 1084, BW2 = 1132, BW3 = 1184, BW5 = 1304 and BW6 = 1370 Hz Px⁻¹. The different BWs were contrast parameters used to study RF artefacts. To achieve a direct comparison, all the

Figure 2. Axial water phantom spin echo-echo planar images show radiofrequency artefacts with different bandwidths (BWs). Note the different BWs and different gaps. From images a-f, axial echoplanar imaging diffusion-weighted imaging at BWs of 1086, 1132, 1180, 1240, 1304 and 1370 Hz Px⁻¹, respectively, depict direct relationships between artefact gap size and BWs. Note that the gap size in the artefact is gradually decreased from images a-e. But there was no difference between images e and f. All images are windowed and levelled identically to show the effectiveness of both algorithms.

other imaging parameters were kept the same for six cases, which were each required to be scanned 13 times. Thus, a total of 78 phantom experiments would be performed. Parallel imaging technology with an acceleration factor 2 was applied additionally in DWI. Owing to the choice of different BWs, there were some minor deviations regarding the measurement parameters for this scanner: the TR was prolonged from 2900 to 3100 ms and the TE was 89 ms instead of 90 ms; the echo spacing (ES) was prolonged from 0.9 to 1.01 ms. 38 slices were imaged simultaneously, which included two *b* values in one BW. At the same time, to keep the persistent disturbance, phantom B (PB) was scanned by an unenhanced MRA-fixed sequence, and the scanning time was 7.36 min in the Symphony scanner with the CP head array coil. All scanning times of PA were recorded. Characteristics of the artefacts in the PA images were recorded. A mid-transverse section (image number 29, *b*₂ value = 1000 s mm⁻²) was chosen for measurement. A straight line was drawn through the centre of PA, which arrived at the inner margins of two parallel artefacts in the image. This straight line was perpendicular spanning the gap between the parallel RF artefacts, which was measured and then recorded.

A mid-transverse section was chosen, and a circular region of interest (ROI) was drawn in the centre of the water PA. Another ROI was put in the background of the FOV. The position and size of these ROIs were identical to minimize individual variations for sequence comparisons. The signal-to-noise ratio (SNR) was then calculated as the mean signal intensity within an ROI divided by the standard deviation of air signal intensity and correction factors.

All statistical calculations and tests were performed by using SPSS® v. 17.0 for Windows (SPSS Inc., Chicago, IL). The artefact

gaps and the quantitative evaluation of SNR and the scanning time were analysed with repeated measures analysis of variance (ANOVA) test. For all tests, a *p* < 0.05 was considered statistically significant.

In vivo studies

The local ethics committee approved this study. Three healthy volunteers (two males and one female; 21, 47 and 65 years old, respectively) were recruited into this study. Informed consent was obtained from the three participants.

Based on PA experiments, we adopted the same acquisition to observe the effect of RF artefacts in EPI DWI *in vivo*. Volunteer 1 was scanned using two kinds of BWs (1240 and 1132 Hz Px⁻¹) on the brain. Volunteers 2 and 3 had abdomen scans with two kinds of different BWs (1730 and 1132 Hz Px⁻¹). Simultaneously, PB was scanned in the Symphony scanner with unenhanced head MRA-fixed sequence.

RESULTS

Phantom results

The RF artefacts can be observed in all EPI DWI. They were symmetrically laid on the two sides of the images, and were stippled or dashed in the phase-encoding direction. Corresponding to each BW, artefact gap sizes were relatively fixed. Mean artefact gap sizes ranged from 17.89 mm to 21.56 mm (Figure 2). The BW was the inverse ratio to the gap between the RF artefacts. The larger the BW became, the smaller the gap became (Figure 3). Using the ANOVA test, there was a significant difference in the gap from BW1 to BW6 (*F* = 298.746; *p* < 0.001). There was a significant decrease in the mean artefact gap size between every

Figure 3. Graph plotting artefact gap against bandwidth (BW) for echoplanar imaging. The trend artefact of gaps decreasing is illustrated.

BW from BW1 to BW6, except between BW5 and BW6 ($p = 0.987$). Maximum gap was formed on BW1 with 1086 Hz Px^{-1} .

A statistically significant difference was found between image SNRs in six cases. The SNR value of PA was significantly decreased with the increasing BW ($F = 3.918$; $p = 0.003$) (Table 1). The scanning time of the lowest BW was 1.16 min (ES, 1.01 ms), routine BW 1.11 min (ES, 0.9 ms) and highest BW 1.14 min (ES, 0.95 ms). However, no statistically significant difference was found in scanning time ($p > 0.05$).

In vivo results

For the three volunteers, EPI RF artefacts on the brain and abdomen images showed hyperintense signals following phase-encoding direction and symmetrical distribution in fixed frequency-encoding direction. For Volunteer 1, scanned using two BWs in the brain DWI, RF artefact gap increased in lower BWs [1132 Hz Px^{-1} (19.86 cm)], which was larger than the conventional BW [1240 Hz Px^{-1} (17.88 cm)] (Figure 4). Volunteers 2 and 3, who had abdomen scans, showed a trend that the RF artefacts gap enlarged with the decreasing BW (Figure 5).

DISCUSSION

Preparation must be made before the installations of multiple clinical scanners at the same site. All installations must abide by the specification to prevent a high-risk orientation, and the

proposed scanner site must be evaluated by professional engineers to prevent problems.⁷ When MR scanners of the same field strength have been installed in the vicinity, the interaction between them must be considered. For two adjacent MR scanners, it is suggested that the two magnet axes are parallel or perpendicular to each other.^{7–11} The implementation of consideration focuses on mutual torques and forces, but the RF interference between the two scanners is overlooked. By being set apart by a large enough separation distance, the placement of our two scanners in a row, with their aperture facing each other, had no effect on the homogeneity of the magnetic field. Based on multiple detections of the site by shielding engineers, the installations of two scanners conform to the existing standard requirement. In this situation, MR RF signals originating from two scanners became the interference sources with proper scanner operation. As a result, for the installation of multiple scanners with the same field strength, we are able to suggest that the specification should be improved and sufficient consideration of RF interference should be performed before proper planning. According to our experience, MR scanners with the same field strength should not be installed in the vicinity of another. The exact safety distance of installation between two MR scanners with the same field strength needs to be studied.

MR scanners of the same field strength in close placement generally would produce severe RF artefacts when half of the sampling rate of the sequence in one scanner is greater than the difference of the centre frequencies between the two scanners. We advise adjusting the difference of the centre frequencies between the two scanners. It is normal to decrease the centre frequency of the scanner to a relatively low centre frequency. With the enlargement of the difference of the centre frequencies, the RF artefacts from the interference between two scanners can be effectively solved. After adjusting the centre frequency of one scanner, we get the more satisfactory effect that RF artefacts have disappeared from the MR images. However, for the few sequences, including DWI EPI, with a larger BW, RF artefacts are still present. Owing to fact that the centre frequency could not be decreased further, we might decrease the number of samples or BWs in the frequency-encoding direction to eliminate the artefacts. Because of the image quality degradation with the decreasing number of samples, which is set with the matrix size, BW is reduced to minimize or eliminate the effect of RF artefacts on the images.

BWs contain transmit BWs and receiver BWs. The transmit BW refers to the RF excitation pulse that will excite the MR signal over slice selection in a pulse sequence, and the slice thickness is proportional to the transmit BW.¹² For one position scans, the transmit BW was decided by the number, thickness of slices and

Table 1. Gap and signal-noise ratio (SNR) of various bandwidths (BW) on echoplanar imaging in the water phantom

BW (Hz Px^{-1})	1084	1132	1184	1240	1304	1370
Gap (cm)	21.56 ± 0.36	20.33 ± 0.33	19.28 ± 0.15	18.43 ± 0.47	17.80 ± 0.29	17.89 ± 0.08
SNR	37.50 ± 7.58	40.52 ± 5.58	36.64 ± 7.04	34.38 ± 5.17	31.93 ± 6.72	31.42 ± 5.61

Significant difference between radiofrequency artefact gaps using analysis of variance test indicates $p < 0.05$, but for 1304 and 1370 Hz Px^{-1} there was no significant difference ($p > 0.05$).

The significant difference between SNRs ($p < 0.05$), especially the obvious overall image degradation was due to increased BW.

There was no significant difference between 1084 and 1132 Hz Px^{-1} ($p > 0.05$).

Data given as mean $\pm$ standard deviation.

Figure 4. Axial spin echo-echo planar images of the brain obtained with an anterior to posterior phase-encoding direction show radiofrequency (RF) artefact [b value = 1000 s mm^{-2} , repetition time/echo time = $3100/93 \text{ ms}$, field of view (FOV) = 230 mm]. Note that (a) extraneous RF noise source, which was from the opposite MR scanner and near the scanner operational frequency, produced linear high signal bands in FOV [bandwidth (BW) = 1240 Hz Px^{-1}] and (b) was the corrected image (BW = 1132 Hz Px^{-1}).

gradient strength.¹³ The range of frequencies acquired by the receiver to sample the MR signal depended on the receiver BW.¹⁴ In general, BW refers to the receiver BW (BW = sampling rate/number of samples).¹² Echoes are obtained along the frequency-encoding direction at the sampling BW rate, and the higher the rate, the greater the range of frequency sampling.¹² The centre frequency of the Avanto scanner is 63.580982 MHz . In DWI, when matrix = 192×192 and BW = 1240 Hz Px^{-1} the receiver BW obtained is $\pm 119 \text{ KHz}$. The frequency ranges from 63.580982 to 63.700022 MHz , including the centre frequency of the Symphony scanner (63.685914 MHz). As the extra signal, the centre frequency of the symphony scanner was just within the range of the Avanto scanner, and the receiver coil took it as RF artefact. For other sequences, the range of the receiver BW was $\pm 16 \text{ KHz}$, so the frequency ranges from 63.564982 to 63.596982 MHz . As a result, no RF artefact appeared.

It has not been reported that this phenomenon of RF artefacts could result from simultaneous application of two adjacent MR scanners in EPI DWI. In our study, multislice single-shot spin-echo EPI acquisitions were selected for head scan with various BWs by means of phantom measurements. In EPI, the entire

k-space is filled with data following one selective RF pulse.¹⁵ After 180° RF pulse, the read-out gradient in EPI oscillates rapidly with positive/negative excursion, resulting in a train of gradient echoes (Figure 6). At the same time, a left/right mirror image is formed along the frequency-encoding direction, but each echo has a different phase encode on the phase-encoding direction by phase-encoded blips.^{2,15-17} Interference RF signals occurring at the same frequency range symmetrically fill in the two sides of the centre frequency and form multiple parallel symmetrical linear stippled or dashed bands in the phase-encoding direction. Our study suggested that the gaps of RF artefacts were mainly affected by different BWs, and our results supported that RF artefact could be gradually moved away from the centre of the image by decreasing the BW within a suitable range. When the BW changed from 1304 to 1086 Hz Px^{-1} , the gap also varied from 17.50 to 21.56 cm . From this trend, the BW is the inverse ratio of the gap between the RF artefacts. Accordingly, the RF artefacts were in the background rather than in the tissue image and avoided affecting the image quality.

It was reported that decreasing BW was an efficient approach to improve the image quality in EPI.^{14,15} Decreasing BW can be used to

Figure 5. Axial abdomen images were obtained with an anterior to posterior phase-encoding direction in different bandwidths (BW) (b value = 800 s mm^{-2} , repetition time/echo time = $1700/73 \text{ ms}$, field of view = 380 mm). (a) Shows more dominant radiofrequency (RF) artefacts that severely disturbed the quality of MR images (BW = 1736 Hz Px^{-1}); (b) illustrates that the gap of RF artefact is enlarged (BW = 1132 Hz Px^{-1}) compared with the uncorrected image.

Figure 6. Schematic of the echoplanar MRI sequence used for our experiments. Within each repetition time period, multiple lines of imaging data are collected. G_x , frequency-encoding gradient; G_y , phase-encoding gradient; G_z , section-selection gradient; K_x , direction of the sampled signal when frequency encoding gradients were applied to the K-space; TR, repetition time.

increase SNR at a constant imaging time or to maintain the SNR for reducing the imaging time.¹⁸ With the parallel technique, the correction factors of 1.5 were used in our experiment for the calculation of SNR to elevate the image quality.^{19–21} An improvement in SNR could be acquired with decreasing BW in our study. This result correlated with the SNR equation, which is inversely proportional to the square root of the receiver BW.^{22,23} It was reported that decreasing the receiver BW allows an increasing TE²² and ES.¹⁴ Although there were changes in TE, ES and scanning time, no obvious statistically significant difference was found in our study. This was the reason why we changed BWs within an advisable range.

The increasing chemical-shift artefact caused by reducing BWs can be eliminated by suppressing the fat signal.¹³ By applying the fat-suppressed pulse as a typical routine before EPI DWI in this study, the fat signal disappeared from the images, so that the frequencies of fat and water were well resolved, and reducing the BW did not produce the obvious chemical-shift artefact.²⁴

There were some limitations in this study. We suspected the integrity of the shielding of the scanner rooms, but this was

proven to be intact after testing by engineers although we could not know definitely whether the shielding is perfect. We have not given the report about the differences between odd number and even number slices in interleaved EPI cases. We have not analysed whether there were differences of RF artefacts between the water phantom and the patient in detail. For the water phantom object, we have not evaluated the effect of chemical shift and contrast to noise ratio on patients. Although we could enlarge the gap between the artefacts or even move it away from the FOV, we could not eliminate the RF artefact. As the problem persists, further study should be carried out.

CONCLUSION

This study shows that two MR scanners in close proximity, which have the same magnetic field and similar centre frequency, can produce RF artefacts when they work at the same time. The image quality of EPI DWI with the wider BW could especially be severely influenced. Although RF artefacts could not be eliminated, they could be moved to the side of the image, and the effect on imaging would obviously be minimized by decreasing BWs within a suitable range.

REFERENCES

- Morelli JN, Runge VM, Ai F, Attenberger U, Schmeets SH, Nitz WR, et al. An image-based approach to understanding the physics of MR artifacts. *Radiographics* 2011; **31**: 849–66. doi: 10.1148/rg.313105115
- Poustchi-Amin M, Mirowsitz SA, Brown JJ, McKinstry RC, Li T. Principles and applications of echo-planar imaging: a review for the general radiologist. *Radiographics* 2001; **21**: 767–79. doi: 10.1148/radiographics.21.3.g01ma23767
- Lin Q, Liang Z, Duan C, Ma J, Li H, Roque C, et al. Motion correction for MR cystography by an image processing approach. *IEEE Trans Biomed Eng* 2013; **60**: 2401–10. doi: 10.1109/TBME.2013.2257769
- Famili N, Wright SM, Porter JR. MR flow measurement using RF phase gradients in receiver coil arrays. *IEEE Trans Biomed Eng* 1993; **40**: 1243–9.
- Harvey JA, Hendrick RE, Coll JM, Nicholson BT, Burkholder BT, Cohen MA. Breast MR imaging artifacts: how to recognize and fix them. *Radiographics* 2007; **27**(Suppl. 1): S131–45. doi: 10.1148/rg.27si075514
- Jahng GH, Weiner MW, Schuff N. Diffusion anisotropy indexes are sensitive to selecting the EPI readout-encoding bandwidth at high-field MRI. *Magn Reson Imaging* 2008; **26**: 676–82. doi: 10.1016/j.mri.2008.01.005
- Pooley RA, Felmlee JP. MRI site planning adventures. *J Am Coll Radiol* 2004; **1**: 871–3. doi: 10.1016/j.jacr.2004.06.013
- Einstein SG, Hilal SK. Site planning design: influences and implementation. *Magn Reson Annu* 1985: 267–311.

9. Andrews DE. Site planning for nuclear magnetic resonance imaging. *Cardiovasc Intervent Radiol* 1986; **8**: 390–3.
10. Lipton ML. Keeping it safe: MRI site design, operations, and surveillance at an extended university health system. *J Am Coll Radiol* 2004; **1**: 749–54. doi: [10.1016/j.jacr.2004.04.016](https://doi.org/10.1016/j.jacr.2004.04.016)
11. Patz S, Mppre WS. The placing of many large superconducting magnets in a limited space. *Magn Reson Med* 1985; **2**: 262–74.
12. Lipton ML. Part II: User friendly: localizing and optimizing the MRI signal for imaging; 7. defining imaging size and spatial resolution. In: *Totally Accessible MRI: A User's Guide to Principles, Technology, and Applications*. Secaucus, NJ: Springer; 2008. pp. 1–6.
13. Mitchell DG, Vinitiski S, Rifkin MD, Burk DL Jr. Sampling bandwidth and fat suppression: effects on long TR/TE MR imaging of the abdomen and pelvis at 1.5 T. *AJR Am J Roentgenol* 1989; **153**: 419–25. doi: [10.2214/ajr.153.2.419](https://doi.org/10.2214/ajr.153.2.419)
14. Giannelli M, Diciotti S, Tessa C, Mascalchi M. Characterization of Nyquist ghost in EPI-fMRI acquisition sequences implemented on two clinical 1.5T MR scanner systems: effect of readout bandwidth and echo spacing. *J Appl Clin Med Phys* 2010; **11**: 3237.
15. Callaghan PT. The influence of magnetic field gradients; rapid sampling of k-space; echo planar imaging. In: *Principles of Nuclear Magnetic Resonance Microscopy*. New York, NY: Oxford University Press; 1991. pp. 152–7.
16. Holdsworth SJ, Yeom K, Skare S, Gentles AJ, Barnes PD, Bammer R. Clinical application of read-segmented-echo-planar imaging for diffusion-weighted imaging in pediatric brain. *AJNR Am J Neuroradiol* 2011; **32**: 1274–9.
17. Liang Z-P, Paul CL; IEEE Engineering in Medicine and Biology Society. Fast-scan imaging; echo-planar imaging. In: *Principles of Magnetic Resonance Imaging: A Signal Processing Perspective*. Bellingham, WA: SPIE Optical Engineering Press; 2000. pp. 303–13.
18. Simon JH, Foster TH, Ketonen L, Totterman S, Szumowski J, Kido DK, et al. Reduced-bandwidth MR imaging of the head at 1.5 T1. *Radiology* 1998; **172**: 771–5. doi: [10.1148/radiology.172.3.771](https://doi.org/10.1148/radiology.172.3.771)
19. Dietrich O, Raya JG, Fellner FA, Reeder SB, Reiser MF, Schoenberg SO. Measurement of signal-to-noise ratios in MR images: influence of multi-channel coils, parallel imaging, and reconstruction filters. *J Magn Reson Imaging* 2007; **26**: 375–85.
20. Kowalski ME, Jin JM, Chen J. Computation of the signal-to-noise ratio of high-frequency magnetic resonance imagers. *IEEE Trans Biomed Eng* 2000; **47**: 1525–33.
21. Wang J, Reykowski A, Dickas J. Calculation of the signal-to-noise ratio for simple surface coils and arrays of coils. *IEEE Trans Biomed Eng* 1995; **42**: 908–17. doi: [10.1109/10.412657](https://doi.org/10.1109/10.412657)
22. Yang RK, Roth CG, Ward RJ, deJesus JO, Mitchell DG. Optimizing abdominal MR imaging: approaches to common problem. *Radiographics* 2010; **30**: 185–99.
23. Giannelli M, Diciotti S, Tessa C, Mascalchi M. Effect of echo spacing and readout bandwidth on basic performances of EPI-fMRI acquisition sequences implemented on two 1.5 T MR Scanners systems. *Med Phys* 2010; **37**: 303–10.
24. Edelman RR, Wielopolski P, Schmitt F. Echo-planar MR imaging. *Radiology* 1994; **192**: 600–12. doi: [10.1148/radiology.192.3.8058920](https://doi.org/10.1148/radiology.192.3.8058920)