Reduced-FOV imaging with *E*xcitation using *N*onl*i*near *G*radient *Ma*gnetic fields (ENiGMa)

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Introduction

In conventional MR imaging strategies, the excitation is localized along a single direction, and the field-of-view (FOV) in the transverse plane is encoded. However, for a considerable number of applications such as cardiac-MRI and functional-MRI, the region of interest may be much smaller than the full-FOV; in this case encoding the full-FOV means increasing the total scan time. Therefore, various methods that enable reduced-FOV imaging have been devised.

Multi-dimensional excitation, refocusing and saturation pulses make use of additional/modified RF pulses to localize the excitation region along more than a single dimension [1-3]. However, such pulses may increase the echo and/or repetition times due to prolonged RF waveforms, and/or preceding RF pulses. Furthermore, a significant increase in SAR is inevitable in all cases. On the other hand, various studies have employed gradient fields with linear or nonlinear distributions in space for refocusing inner volumes [4-5] or dephasing outer volumes [6], thereby decreasing the field-of-view. Although the latter approach does not alter the SAR, increases in the echo and repetition times may be unavoidable due to the additional gradient waveforms, especially in fast sequences such as fast-low-angle-shot (FLASH).

Last year, we introduced a novel FOV reduction technique that employs nonlinear gradient fields during excitation [7]. In [7], which was a proof-of-principle study, the effect of a nonlinear gradient field on the excitation profile was demonstrated by altering the default shim magnetic fields of the scanner. However, because of the low field values generated by the shim coil, the RF pulse duration was significantly increased. Furthermore, the lack of real-time control of the nonlinear magnetic field resulted in an ever-present static magnetic field perturbation, leading to continuous spin dephasing. Recently, we have implemented the idea on a transmit-array architecture that provides real-time control of the nonlinear magnetic field and with additional high-power gradient amplifiers that allow higher field amplitudes. In this study, the implementation of the proposed algorithm in a conventional imaging scheme is presented.

Theory

In MRI, selective excitation is performed by transmitting a band-limited RF pulse in the presence of a gradient field. When a single linear gradient field is employed, the excitation is selective along a single direction. Because nonlinear gradient fields vary along at least two directions, playing a band-limited RF pulse yields an excitation that is selective in at least two directions when a nonlinear gradient field is present.

When the FOV is smaller than the excitation region, folding artifacts occur, which may reduce the diagnostic quality of the image. Although such effects may be destructive in conventional approaches, they may be harmless when nonlinear gradient fields are used. With a proper selection of encoding directions, such artifacts can be directed towards the readout direction, and discarded using simple post-processing techniques, which is the backbone of the idea presented in this study.

Methods

Imaging was performed on a Siemens 3T TIM Trio with additional gradient amplifiers and a transmit array architecture (Siemens Healthcare, Erlangen, Germany). A gradient insert coil (Resonance Research Inc., MA) large enough for neuroimaging, that generates the Z2 harmonic field (z^2-x^2/2-y^2/2) is used for excitation of a cylindrical ROI (height: 2.2 cm, diameter: 3 cm) inside a cylindrical phantom (height: 17.2 cm, diameter: 20.3 cm, J7239, JM specialty Parts, San Diego, CA). The images of the phantom are shown in Fig. 1 whereas Fig. 2 shows the excitation profile.

A 3D FLASH sequence (Siemens Healthcare, Erlangen, Germany) was modified such that it contained no slice selection or slice rephaser waveforms, while the RF pulse was unaltered. Another copy of the same sequence was modified such that it controlled slice selection and rephaser waveforms that were fed to the nonlinear gradient coil using the transmit-array architecture. The sequence parameters were as follows: RF pulse: an apodized sinc pulse with a time-bandwidth product of 2.7 and a duration of 4.1 msec, TE/TR: 6.1/12 msec, flip angle: 5°, resolution: 1 mm isotropic, $FOV_{x\text{-}y\text{-}z}$: 64 x 64 x 256 mm^3 with readout along *z*, number of averages: 16.

Results

In slab imaging schemes, the transition regions are encoded but discarded. For the RF pulse used in the experiments, a minimum $FOV_{x\text{-}y\text{-}z}$ of 203 x 203 x 52 mm^3 needs to be encoded, including the transition regions along *z*. With readout encoding performed along *x* or *y*, the total scan time needed is 126 sec without averaging. For the 64 x 64 x 256 mm^3 FOV used in the experiments for the proposed scheme (Figs. 3-4), the total scan time without averaging was 49 sec, which is 61% lower than the linear case. It should be noted that, the transition regions exist in both the *x* and *y* directions for the proposed scheme. However, the second order field variation causes the transition regions to contract, yielding a minimum FOV of 48 x 48 x 172 mm^3, which leads to a minimum scan time of 27 sec, which is 79% lower than the reference case.

Discussion and Conclusion

The method provides reduced-FOV imaging capabilities without altering the SAR or the echo/repetition times. The reduction in scan time depends on the ratio of the volume of interest and the subject volume. Therefore, higher reductions can be achieved with the proposed method. Furthermore, the method is compatible with parallel imaging techniques such as SENSE [8]. Although the reduction in total acquisition time is accompanied by an overall reduction in SNR as expected, the method does not increase the g-factor as opposed to parallel imaging strategies.

The method is demonstrated using a full-power gradient amplifier and a nonlinear head gradient coil for the first time, using phantom experiments.

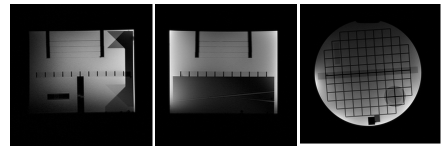

Figure 1: Gradient echo images of the contrast phantom used in the experiments on (left) sagittal, (center) coronal and (right) axial planes.

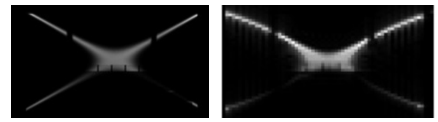

Figure 2: Excitation profiles on the coronal plane, (left) expected, (right) realized, low resolution.

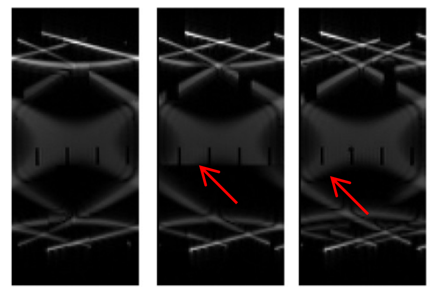

Figure 3: Images demonstrate the folding artifacts when the FOV is reduced. (left) sagittal, (center) coronal (right) shifted coronal planes. The effect of the contrast phantom can be seen when two coronal plane images are compared (indicated).

Figure 4: Zoomed axial image of the central region shows that the central region is not affected by the folding artifacts.

References

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