Magnification Imaging by Radiofrequency-Induced Nonlinear Phase Encoding

Jun Shen[1]
[1]*NIMH, Bethesda, MD, United States*

Target audience MR physicists who are interested in new imaging methods

Purpose The purpose of this work is to introduce a new imaging technique for resolution enhancement. This new technique essentially stretches a predetermined region of interest in the object to be imaged by interacting linear magnetic field gradients with a series of specially designed radiofrequency magnifying pulses. These magnifying pulses progressively bend the phase of electromagnetic signals from the imaging focus during phase encoding. As a result, differential phase evolution at the imaging focus is faster than in conventional MRI. Since Fourier transform image reconstruction evenly divides phase space into pixels, the imaging focus is filled with more pixels, leading to focal resolution enhancement at the region of interest.

Methods NMR experiments were performed on an 11.7 T scanner interfaced to an 89-mm bore vertical magnet. A 38-mm i.d. birdcage coil and a home-built single-turn 1.5-cm i.d. surface RF transmit/receive coil were used for phantom and in vivo imaging of rat brain, respectively. The magnifying pulses have a phase profile described by integer*φ(r). Examples of magnifying pulses generated by Fourier transform[1] were given in Fig. 1. The magnifying pulses excite a slab of magnetization covering the FOV. A refocusing pulse with its gradient perpendicular to the slab gradient was used for slice selection (slice thickness: 2 mm). A total of 128 magnifying pulses (T_p = 2.7 or 3.2 ms; nominal flip angle 36 ~ 45°) for 256 (readout) x 128 (phase encoding) or 384 (readout) x 128 (phase encoding) images were implemented for each imaging experiment. The time domain data were Fourier transformed to generate a raw magnified image. The raw magnified image is first multiplied by |dφ/dr| along the phase encoding direction. Then the raw image was regridded according to r = r(φ). To minimize regridding error the image matrix size was expanded by 64-128 folds in the phase encoding direction. Computer programs were developed in-house for RF pulse design, numerical simulations and image processing.

Results Fig 2 top left panel showed a conventional spin echo image of a comb-like phantom. The top middle panel shows the raw magnified image with 2x magnification with the same matrix size. The imaging focus was placed at the center tooth. The top right panel shows the regridded image where the edges of the center tooth were sharpened due to focal magnification. The bottom panel shows the one-dimensional profile of the blue line in the top left panel where the center tooth was defined by two points. In the magnified image the center tooth was defined by four points. In Fig. 3, the left image was a conventional spin echo horizontal image of rat brain. The right image was the regridded magnified image with the imaging focus placed at the brain midline (magnifying power: 2x). Fig. 4 shows the effect of three-fold in vivo magnification imaging. In Fig. 4 (right), anatomical details at inferior and superior colliculi as well as hippocampal formation were clearly magnified.

Discussion and Conclusion In contrast to parallel and compressed sensing MRI the magnification imaging technique described here relies on Fourier transform for image reconstruction. Further imaging processing is based on predefined magnetization phase profile where an arbitrarily large number of pixels can be used for regridding. More sophisticated RF pulse design is expected to increase the magnifying power of this technique and allow multi-foci magnification. Since the raw magnified image is a Fourier image with uniform spatial resolution magnification imaging can be readily combined with parallel imaging whereas imaging acceleration or resolution enhancement from these two independent techniques multiplies.

References 1. Warren WS, Silver MS. Adv. Magn. Res. 1988; 12:248–384.

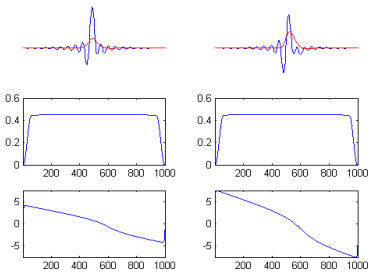

Fig. 1. Top trace: Examples of radiofrequency pulses that bend magnetization phase (blue: real; red: imaginary); Middle trace: M_{xy}; Bottom trace: Magnetization phase (radian). Imaging focus is off-centered at point #620.

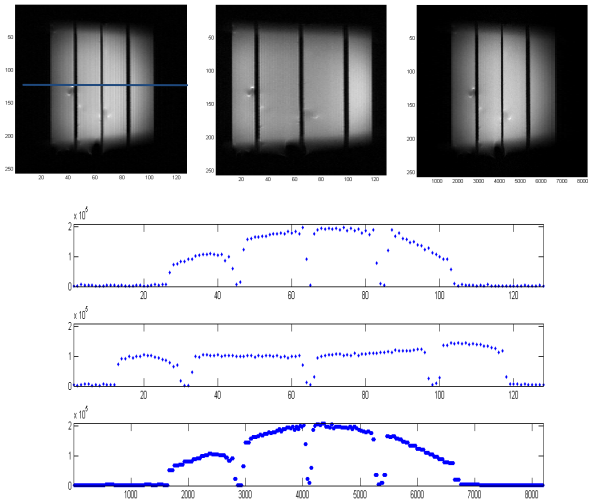

Fig. 2. FOV: 32 x 32 mm^2. Matrix: 256 x 128. TR/TE: 500/11 ms. Top panels: (Left) Conventional spin-echo image. (Center) Raw magnified image. Magnifying power: 2x. (Right) Image regridded to 8192 in phase encoding direction. Bottom panel: One-dimensional image of the blue line across the comb. (Top) Conventional image. The center tooth was defined by two points. (Middle) Raw magnified image. The center tooth was defined by four points. (Bottom) Regridded image.

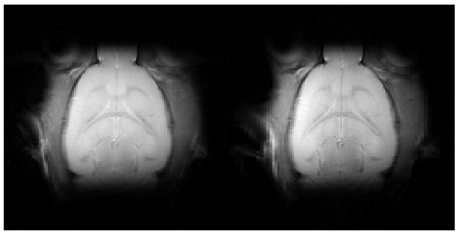

Fig. 3. FOV = 29 x 29 mm^2. Matrix: 256 x 128. TR/TE: 750/22 ms. NA: 1. Left: Conventional spin-echo image. Right: Magnified image (magnifying power: 2x; regridded to 8192 in phase encoding direction).

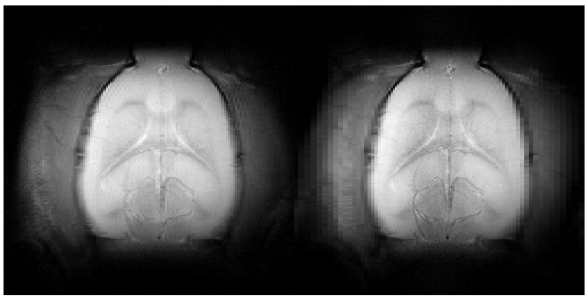

Fig. 4 FOV = 25 x 25 mm^2. Matrix: 384 x 128. TR/TE: 500/24 ms. NA: 2. Left: Conventional spin echo image. Right: magnified image (magnifying power: 3x; regridded to 16384 in phase encoding direction).