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Magnetic resonance imaging phase encoding: A pictorial essay

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A set of MRI images with various degrees of phase encoding were generated from the same raw data set. The resultant pictorial teaching aid is useful in developing an intuitive understanding of the mechanics and principles of phase encoding in two dimensional, Fourier transform magnetic resonance imaging.

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Introduction

The most common technique of magnetic resonance image formation is *two dimensional Fourier transform* (2DFT) reconstruction *(1)*, also known as *spin warp imaging (2)*. To obtain images of a plane or section from within a patient, 2DFT imaging requires the use of slice selection, frequency encoding, and phase encoding gradients *(3–8)*. The technique of phase encoding is foreign to other modes of image production in diagnostic radiology and can be confusing even to those well versed in CT projection reconstruction or other image reconstruction methods.

The images contained in this paper present a pictorial teaching aid for understanding phase encoding. The images incorporate various amounts of phase encoding from 2 to 256 phase encoding steps (Figures 1–12) and have been reconstructed from a single original data set. Images reconstructed at various levels of phase encoding show image sharpness to improve as the number of phase encoding steps increases and give one a subjective "feel" for image clarity resulting from higher phase encoding views.

Materials and Methods

A 1.5 Tesla magnetic resonance imager (GE Signa, Milwaukee, WI) was used to provide the original raw data. The data were acquired in the sagittal plane using a spin echo pulse sequence with TE of 25 msec, TR of 500 msec, 2 excitations, 256 phase encoding views, 10 mm slice thickness, and a 24 cm field of view. Phase encoding was performed in the anteroposterior direction. Copies of the original raw data set were truncated to provide data at 2, 4, 8, 12, 16, 24, 32, 48, 64, 128, 192, and 256 phase encoding views (centered about zero) prior to image reconstruction. These truncations produce ringing or Gibbs artifacts which are noticeable in some images. All images were printed with a window width of 300 and a window level of 1200.

Discussion

The anatomical details found in the original sagittal image represent the usual clinical range of spatial frequencies (sharp and smooth structures). The degree of phase encoding plays a role in the representation of these structures. For equal clarity, smooth structures containing low spatial frequencies are faithfully rendered with fewer phase encoding steps than sharp structures containing high spatial frequencies.

It is important to note that every view of a magnetic resonance image is the same except for the phase encoding gradient. The phase encoding gradient is pulsed "on" briefly during the acquisition at different amplitudes for each view. The gradient magnetic field is superimposed on the main magnetic field, causing a difference in magnetic field across the image in the phase encoding direction. This allows the spin system to precess at slightly different frequencies for a short period of time, effectively leaving a "twist" of the system's magnetization vectors when the phase encoding gradient is removed. Figure 13 is a diagrammatic representation of zero, 2π, 4π, and 8π radian twist across the field of view. The amount of twist or phase encoding is reflected in the echo amplitude for each view; and is decoded into spatial information by 2DFT image reconstruction.

Many good references on the physics of phase encoding are available. We have intentionally eschewed further detailed diagrams in order to focus attention upon image representation, and we refer the interested reader to the cited literature for further details on the physics of spin warp imaging.

The images presented here have been helpful in teaching the concept of phase encoding. A pictorial representation has resulted in increased awareness on the part of those unfamiliar with this topic. By examining the range of phase encoding (2 through 256 views), an intuitive sense for the direct result of increased or decreased phase encoding can be gained.

Figure 1
MR image with 2 phase encoding steps.

Figure 2
MR image with 4 phase encoding steps.

Figure 3
MR image with 8 phase encoding steps.

Figure 4
MR image with 12 phase encoding steps.

Figure 5
MR image with 16 phase encoding steps.

Figure 6
MR image with 24 phase encoding steps.

Figure 7
MR image with 32 phase encoding steps.

Figure 8
MR image with 48 phase encoding steps.

Figure 9
MR image with 64 phase encoding steps.

Figure 10
MR image with 128 phase encoding steps.

Figure 11
MR image with 192 phase encoding steps.

Figure 12
MR image with 256 phase encoding steps.

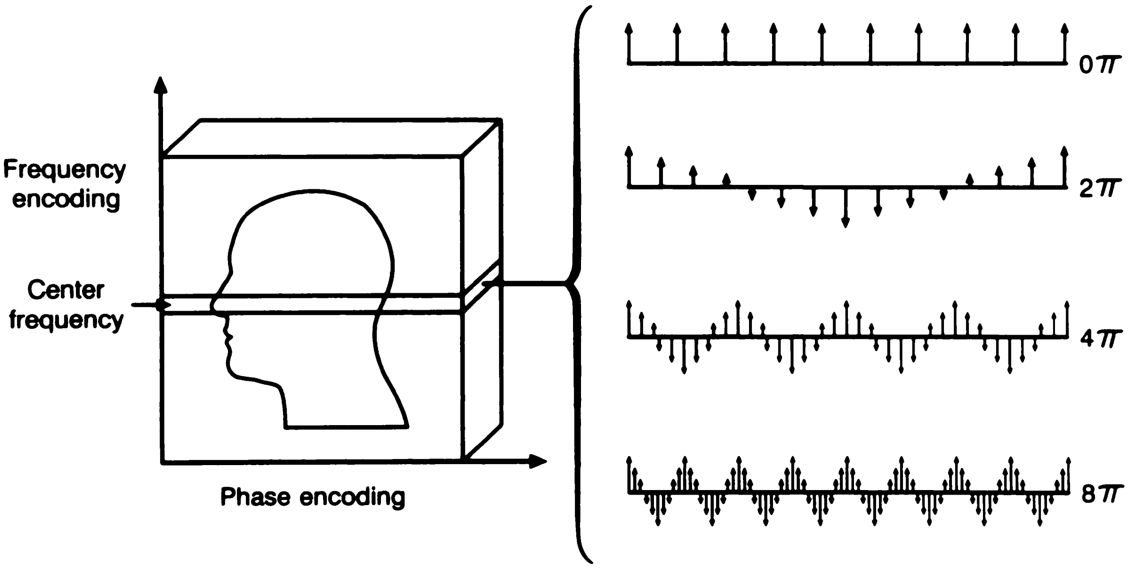

Figure 13
Magnetization vector diagrams are shown for the spin system defined by the image center frequency and reflect the "twist" caused by zero, 2, 4, and 8 radian phase encoding. Although only a single frequency is represented here, this effect will occur for all frequencies in the image.

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