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# Frequency Shift Artifacts in MR Imaging

Andrew J. Dwyer, Richard H. Knop, and D. I. Hoult

**Abstract:** Chemical shifts may be expressed as distortions and displacements in magnetic resonance (MR) images. Specifically, in two-dimensional Fourier transform reconstructions such shifts produce visible displacements in the direction of frequency encoding. This is readily observable at 0.26 T with phantoms comprised of in vitro solutions with known chemical shifts and human tissues with disparate fat content. Moreover, frequency shift artifacts are visible in routine abdominal scanning at the interfaces of structures of differing fat content. Two common examples of this involve the vertebral body and intervertebral disk and the kidney and surrounding retroperitoneal fat. Without appropriate changes in gradients, such distortions may be expected to increase with increasing magnetic field strength. **Index Terms:** Artifacts—Chemical shift imaging—Nuclear magnetic resonance.

At present, clinical magnetic resonance (MR) imaging is designed to produce images with high spatial content but with the sacrifice of chemical information. Presumed in data acquisition and image reconstruction are negligible chemical shifts among the structures imaged. One might predict the presence of nonnegligible chemical shifts to be expressed as distortions and displacements in MR images. To test this hypothesis we initially scanned in vitro solutions with known shifts and used a magnitude display to eliminate the possibility of phasing artifacts. The demonstration of a marked artifactual distortion of the image prompted a search for, and a demonstration of, analogous frequency shift artifacts both in a more "physiologic" experiment and in clinical scans. This article is an explanation and demonstration of our results.

## MATERIALS AND METHODS

In planar imaging by two-dimensional Fourier transform methods, spatial information is encoded in terms of frequency in one axis and in terms of phase in the other. Hence, anomalous frequency changes, caused by chemical shift differences between structures, may be expressed as artifactual displacements in the images of those structures relative to one another, in the direction of frequency encoding. Such a displacement was experimentally verified (Fig. 1). Displayed are the scans at 11 MHz (with vertical frequency encoding) of two beakers, each containing a 1 cm test tube. The upper beaker and tube contain water, whereas the lower beaker contains $H_2SO_4$ and, in its test tube, tetramethylsilane (TMS). The TMS tube was displaced downward from its true position relative to the beaker by 3 pixels (3.5 mm) as would be predicted by a relative chemical shift of 11 ppm, and the resolution achievable with a data acquisition window of 24 ms. Notably, the shift produced a crescentic signal void adjacent to the tube by producing a spurious gap between the test tube and the surrounding solution. Figure 2 demonstrates a similar result obtained under similar conditions with a more "physiologic" phantom comprising a test tube containing human muscle embedded in a beaker of human adipose tissue. The test tube is factitiously displaced upward in the image. Spurious overlap of muscle on fat at the upper margin and spurious separation of muscle from fat at the lower margin produce crescents of increased and decreased signal intensity, respectively. Assuming a readout gradient of 440 Hz/cm, the observed displacements exceed slightly those expected at 0.26 T (i.e., 2.8 mm with TMS and 0.95 mm with fat-muscle, assuming shifts of 11 and 3.5 ppm, respectively). Such discrepancies between observed and predicted may result, at least

From the Department of Diagnostic Radiology, Clinical Center (A. J. Dwyer and R. Knop), and Division of Research Services, Biomedical Engineering and Instrumentation Branch (D. I. Hoult), National Institutes of Health, Bethesda, MD. Address correspondence and reprint requests to Dr. A. J. Dwyer at Department of Diagnostic Radiology, Clinical Center, Building 10, Room 1C660, National Institutes of Health, Bethesda, MD 20205, U.S.A.

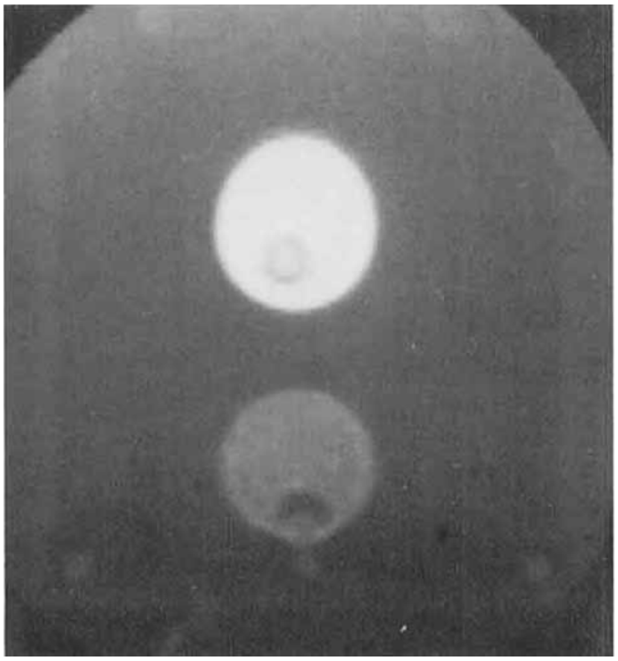

**FIG. 1.** Image of a phantom comprised of two beakers each containing a 1 cm test tube. The lower test tube is spuriously displaced downward relative to the beaker because of the chemical shift between its content, tetramethylsilane, and the water in the beaker. No such displacement is seen between the upper test tube and beaker, both of which contain water ("brighter" than the lower due to doping with copper sulfate).

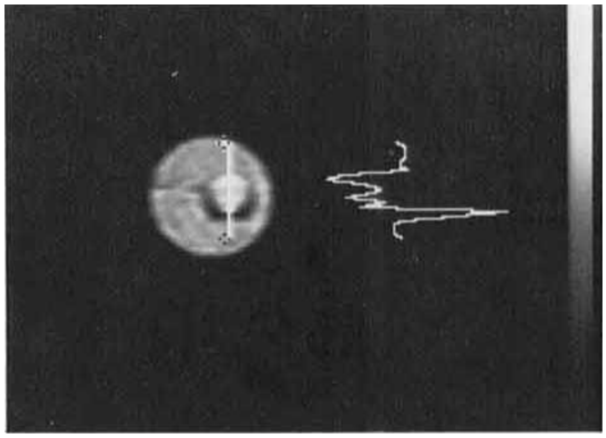

**FIG. 2.** Image demonstrates spurious upward displacement of a test tube containing human muscle embedded in a beaker containing human fat. The displacement has produced a crescent of diminished signal on the lower surface of the test tube because of an artifactual gap between the muscle and fat. On the upper surface a crescent of increased signal intensity has appeared because of artifactual superimposition of muscle on fat. These are reflected as a valley and peak in the "profile" of signal intensities displayed vertically to the right.

**FIG. 3.** Sagittal SE 40/600 image of the vertebral column demonstrates a band of diminished signal intensity at the cephalic end of each vertebral bodies.

in part, from the finite size of the pixels, the imperfect spatial resolution, and the tendency of such border features to be blurred and thickened in the image.

We have found what we believe to be frequency shift artifacts in routine abdominal scanning at 0.26 T. Understandably, these occur at the interfaces of structures having different chemical shifts, presumably due to differing fat content. One example involves, as shown in Fig. 3, the vertebral column and the relation between disk and vertebral body. The sagittal image shown [spin echo (SE) 40/600] demonstrates considerable disparity in the appearance of the caudal and cephalic margins of the vertebral bodies. Specifically, the cephalic end of each body demonstrates a well-defined band of diminished density not present on the caudal end. Since frequency encoding is longitudinal, this would be explained by a caudal displacement of the vertebral body, which commonly contains fat, relative to the disk. This would create an artifactual gap and signal void between the cephalic margin of the vertebral body and the disk. At its caudal end, the "displaced" vertebral body overlaps and obscures the endplate and disk margin. The direction of this spatial shift of the vertebral body is determined by the frequency shift between fat and disk and the orientation of the field gradients. As shown in Fig. 4, reversal of the gradients by reversing the patient's position in the scanner reverses the appearance of the artifact. Now the band of diminished signal involves the caudal surface of the vertebral body due to cephalic shift of the body relative to the disk.

**FIG. 4.** Sagittal SE 80/1,700 image of the vertebral column demonstrates a band of diminished signal intensity at the caudal end of each vertebral body.

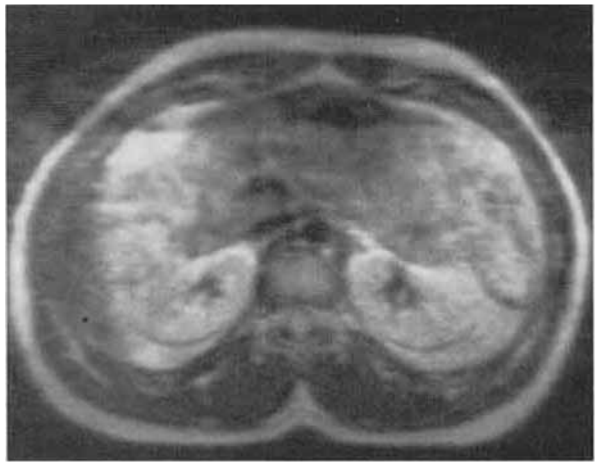

**FIG. 5.** Transverse (SE 80/1,700) image of the upper abdomen demonstrates frequency shift artifacts involving the kidneys. Thin crescentic margins of diminished signal intensity are seen at the posterior borders of the kidneys due to spurious anterior displacement of the kidneys relative to the adjacent fat producing an artifactual anatomic gap. A margin of increased signal intensity is seen at the anterior border of each kidney because of spurious anterior displacement of the kidney and superimposition of kidney on fat.

A second artifact shown in Fig. 5 involves kidneys and adjacent retroperitoneal fat. The scan (SE 1,700/80) is a transverse section through the upper abdomen, depicting each kidney with a margin of high signal intensity on the anterior border and margin of low signal intensity on the posterior border. Since the direction of frequency encoding is vertical, this pair of artifacts would be explained by slight factitious displacement of the kidney anteriorly relative to the fat. This would produce an artifactual anatomic gap between kidney and fat and a decrease of signal posteriorly, and artifactual overlapping of kidney and fat and an increase of signal anteriorly. Moreover, we have observed that a change in the axis of frequency encoding, from the vertical to horizontal, shifts the boundaries affected from anteroposterior to mediolateral.

## DISCUSSION

Review of images included in a number of published articles has demonstrated similar artifacts using different instruments and field strengths (1,2). The clinical implications relate to the resulting inaccurate depiction of the anatomic boundaries and distortion of spatial relationships. The potential for confusing such artifacts with real anatomy or pathology might be reduced by considering the possibility of frequency shifts between the structures involved, identifying the paired nature of the artifacts produced, and demonstrating a change in orientation of the artifact with a change in direction of frequency encoding. Although this discussion has been confined to artifactual displacement within the plane of scanning, the problem also involves the third dimension since structures, due to chemical shift differences, may be artifactually included in, or excluded from, a given slice during the slice selection process. The imaging implications are that these distortions can be expected to increase with increasing magnetic field strength if the data acquisition window is kept constant without appropriate changes in the gradients.

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