Biopsy Needle Susceptibility Artifacts in Magnetic Resonance Imaging

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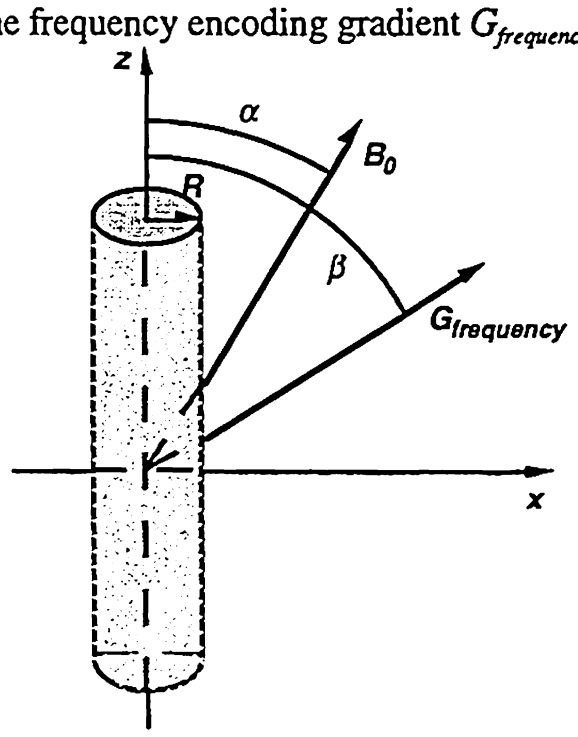
Introduction

Magnetic resonance imaging is attracting attention as a potential interventional monitoring modality. MRI-guided biopsies are one of the simpler interventional procedures. One possibility is to directly visualize the needle with MRI. However, its appearance is largely determined by the susceptibility artifact.

This paper presents the results of computer simulations of the image distortion resulting from the magnetic susceptibility difference between the needle and the surrounding tissue. The simulations show not only an artifact size which is dependent on needle composition, orientation, and pulse sequence, but also a corresponding shift of the artifact center away from the actual needle center. This shift places limits on the accuracy of needle tip placement.

Theory

The needle is modelled by assuming an infinite cylinder of permeability μ_i and radius R in a uniform magnetic field B_0. The cylinder has its axis parallel to the z-axis as shown. The angle α represents the orientation of the magnetic field with respect to the needle, and the angle β the orientation of the frequency encoding gradient $G_{frequency}$.



The magnetic field external to the cylinder is

$$\hat{\mathbf{x}}B_0\left[1+R^2\left(\frac{\mu_i-\mu_e}{\mu_i+\mu_e}\right)\left(\frac{x^2-y^2}{\left(x^2+y^2\right)^2}\right)\right]\sin\alpha+$$

$$\hat{\mathbf{y}}B_0\left[2R^2\left(\frac{\mu_i-\mu_e}{\mu_i+\mu_e}\right)\left(\frac{xy}{\left(x^2+y^2\right)^2}\right)\right]\sin\alpha+\quad , \qquad [1]$$

$$\hat{\mathbf{z}}B_0\cos\alpha$$

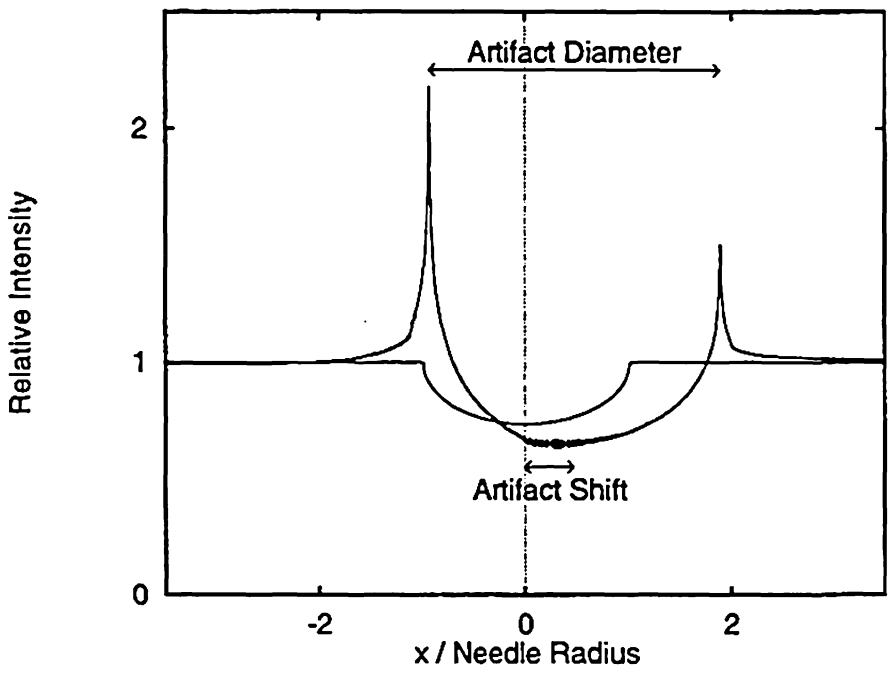
where μ_e is the permeability of the material surrounding the cylinder.

When objects with different magnetic susceptibilities are imaged, local magnetic field inhomogeneities are introduced which cause spatial and intensity distortions (1). Using Eq. [1], the distortion of voxels outside the cylinder can be calculated as a function of α, β, and the dimensionless parameter

$$\eta=-\left(\frac{\mu_i-\mu_e}{\mu_i+\mu_e}\right)\frac{B_0}{RG_{frequency}}. \qquad [2]$$

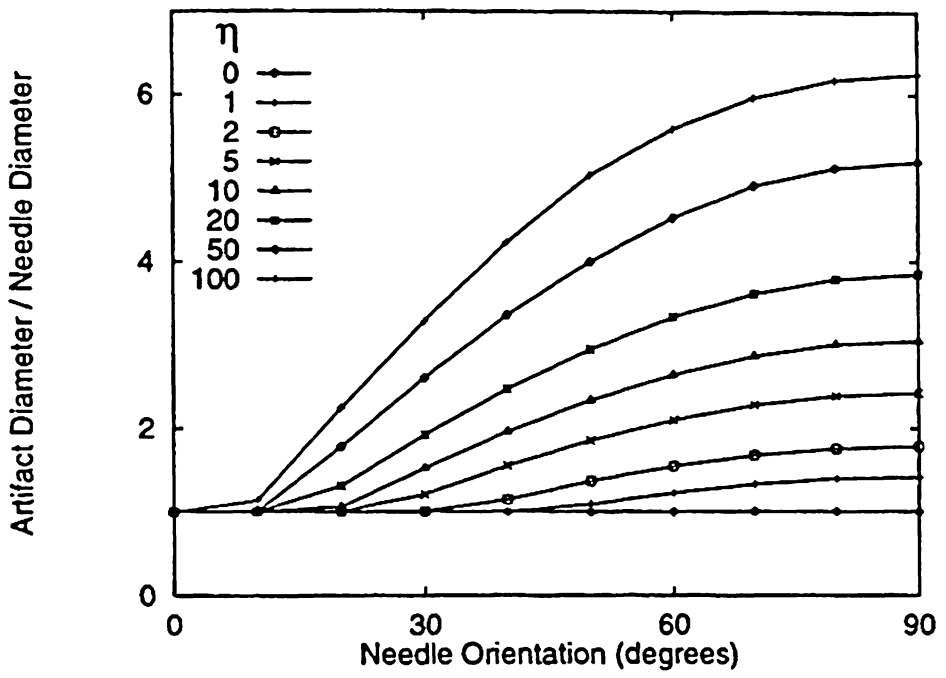
Methods

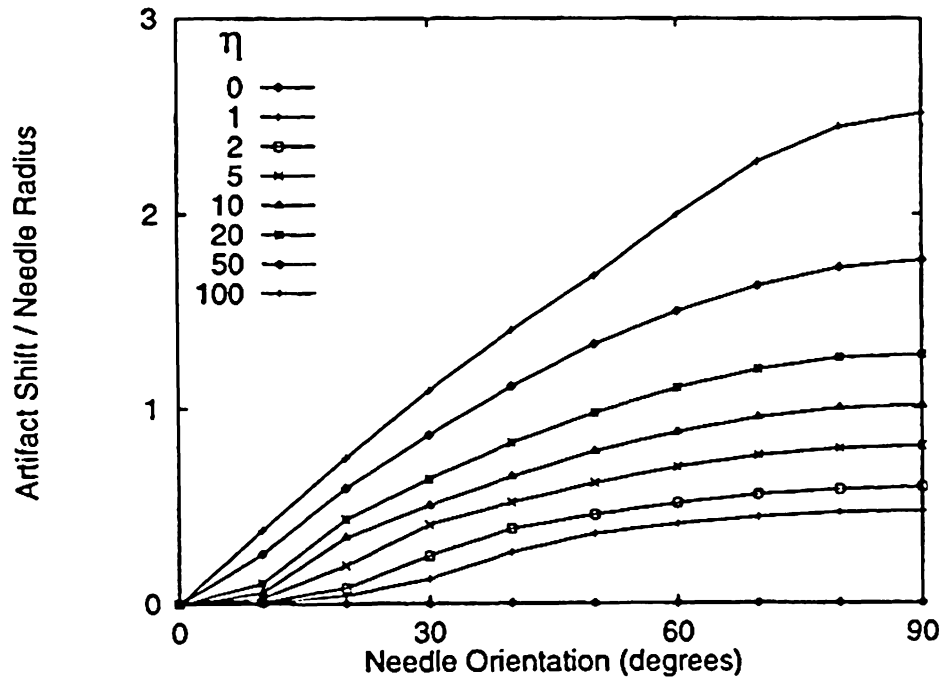
Spatial distortions were simulated for an image in the xz-plane and intensity profiles along the x-axis were calculated. The distortion creates two peaks in the profile which delineate the apparent extent of the needle. From these profiles, two attributes were defined. The first was the artifact diameter, which was taken to be the distance between the two peaks. The second was the artifact shift, which was defined to be the difference between the cylinder center and the midpoint of the two peaks.



Results

Below is a plot of artifact diameter, normalized to needle diameter, versus α (needle orientation) for various η's. The frequency encoding was kept parallel to B_0 (β=α). As expected, the artifact size increases with increasing η. Also, since the susceptibility artifact is in the frequency encoding direction, the artifact increases with α for a given η. The second plot shows the corresponding artifact shift, normalized to needle radius.





Discussion

Passive visualization of very thin structures without utilizing the susceptibility artifact is difficult in MRI. However, structures which cause a large enough artifact to be easily seen in an image distort the surrounding anatomy to such an extent that important information for the interventionist can be obscured. Further, these artifacts are very orientation dependent.

With this simulation tool, orientation and pulse sequence dependent biopsy needle artifacts can be studied. The above results show that in addition to the problem of artifact size not being constant, the artifact is not always centered on the physical needle. This could lead to false needle placement if one relies only on passive visualization.

Acknowledgments

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References

[1] K.M. Lüdeke, et al.; *Magn. Reson. Imaging* 3, 329, (1985)