Torque and Translational force Considerations for ferromagnetic shells in MR Imaging

Vahid Ghodrati[1] and Abbas N Moghaddam[1,2]
[1]BME, Tehran Polytechnic, Tehran, Tehran, Iran, [2]School of Cognitive Sciences, Institute for Studies in Theoretical Physics and Mathematics, Tehran, Iran

Purpose

MRI is a powerful system in the Medical Imaging that provides the highest contrast between soft tissues with no known adverse effect in the absence of ferromagnetic objects. However, in some injuries, such as those happen in the battle field, part of shells or foreign objects that may include magnetic materials remain in victim's body. This is considered a serious contraindication for MRI scan since the shell may move or rotate in the strong static magnetic field. In particular, if the shell is in the head region, the effect of this motion or torque may cause an irreversible defect. In general torque makes a greater health risk compared to the translational force [1]. Since the shape and material of these objects are unknown, a shape classification that covers the most problematic situations is helpful. For calculation of the translational force we may only focus on spherical geometry, however, for approximation of torque a more general shape like an ellipsoid is required. "Ellipsoid of revolution" has an axis of symmetry and two equivalent principle axes. Here we present the force and torque estimation for a ferromagnetic object using these general shapes and discuss the worst case scenario that may occur for these patients.

Method

Translational force and torque on a ferromagnetic ellipsoid of revolution with χ>>1 is independent from susceptibility and rely on geometrical factors according to the following conventional approximations [1]:

$$F_z = \frac{V}{\mu_0} B_0 \frac{\partial B_0}{\partial z}\left[\frac{(cos\theta)^2}{D_a} + \frac{(sin\theta)^2}{D_r}\right] \quad (1) \qquad T_y = \frac{VB_0^2}{\mu_0} \times \frac{D_a - D_r}{D_a D_r} \times \sin\theta\cos\theta \quad (2)$$

where V is the volume of object, θ is the angle between applied field and the axis of symmetry. D_a and D_r are the demagnetizing factors, respectively along the axis of symmetry and the radial directions. For the cylindrical shell with length of L and radius of R, they can be easily obtained: $D_r = \frac{1}{2L}\left[\sqrt{L^2+R^2} - R\right], D_a = 1 - \frac{1}{L}\left[\sqrt{L^2+R^2} - R\right]$. For a ferromagnetic spherical object $D_a = D_r = 1/3$ and no torque may occur. Therefore we used this geometry to obtain a range of translational force which is in this case simplified to $F_z = \frac{3V}{\mu_0} B_0 \frac{\partial B_0}{\partial z}$ (3). The field distribution along the z-axis was derived from the fringe field map of a commercial scanner (AVANTO-1.5T-Siemens). A sum of six gaussian functions was fit to that map to make the analytical calculations possible (figure1).

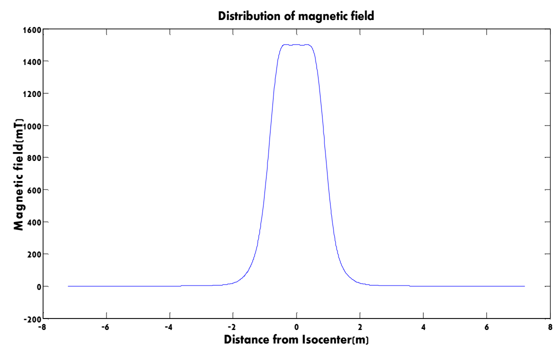

Figure 1. B_0 field distribution

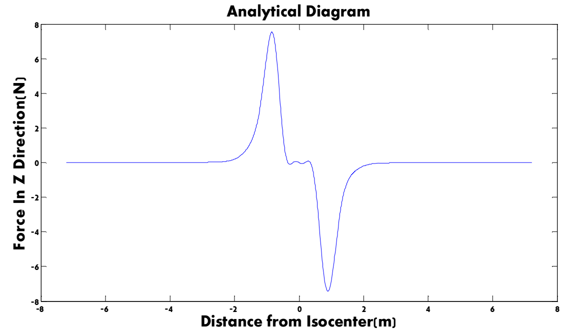

Figure 2. Translational force

Results

According to the Eq(3) we achieved a translational force plot for a spherical metal. Figure 2 illustrate this plot for r = 6 mm at B_0 = 1.5 Tesla. The torque for a cylindrical object was also approximated, according to Eq(2). The approximated torque depends on B_0, D_a, D_r and θ. The maximum torque value for the ellipsoid occurs at θ=45 deg when the object is near the isocenter of the scanner. Table (1) summarizes the maximum torque value for a cylindrical object with V=1cm^3 based on the different possible $\frac{L}{R}$ ratio.

Table 1. torque result for reasonable L/R ratio of cylindrical object

L/R	.1	.2	1	5	10
D_a	.950	.900	.585	.180	.095
D_r	.0249	.049	.207	.409	.452
T_y(N.m)	34.97	17.097	2.795	2.785	7.447

Discussion and Conclusion

Translational force reaches its maximum value outside but close to the opening of the bore. There is no translational force acts on the ferromagnetic spherical objects near the Isocenter, since the undistorted magnetic field is almost constant in that area. In contrast, the torque is maximum inside the magnet and considering the high magnetic field inside the bore, torque can be much more important. For a long cylindrical shell where L>>R (D_r→1/2, and D_a→0) or for a flat cylindrical shell like a disk with L<<R (D_a→1, and D_r→0), the torque goes to infinity but these extremens are not realistic shapes for foreign objects. In realistic conditions, it is very unlikely to have any L/R ratio outside the ranget that is covered in Table 1. The torque can be greatly reduced by changing the angle θ between the axes of the object and the scanner. A prior knowledge about the shape geometry and angle, for example obtained by a simple X-ray imaging, can substantially help with ensuring the safety of the MR imagin.

References:

1. *John F.Schenck, "Safety of Strong, Static Magnetic Fields", J.Magn.Reson.Imaging, 2000.*