Derived MRI induced Maximum Torque (ASTM F2213) from measured MRI induced Maximum Force (per ASTM F2052)

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Target Audience: Medical device manufacturers, medical device laboratories, regulatory agencies

Purpose: MR safety and MR conditional safety of medical device implants rely on a number of standard test methods. Two test methods, the magnetically induced force test method (ASTM F2052) and the magnetically induced torque test method (ASTM F2213) are typically part of the MR safety testing. The equations governing magnetic force and magnetic torque share many common terms[1]. Hence, we hypothesized that the magnetically induced torque could be calculated in terms of the measured magnetically induced force, thus eliminating the need to measure the magnetic torque per ASTM F2213 for all cases in which opposing static magnets are not present in the device.

Methods: The magnetic force and magnetic torque equations from their respective test methods were obtained:

$$F_{mag} = \frac{M_s V}{\mu_o} \nabla B \qquad \tau_{mag} = \frac{{M_s}^2}{2\mu_o}(N_n - N_t)V$$

The magnetic torque was then derived in terms of the magnetic force by replacing $M_s V$ in its terms from the magnetic force equation into the magnetic torque equation. In this equation, the magnetic torque (τ_{mag}) is dependent on the magnetic saturation of the device (M_s) and the magnetic force (F_{mag}) for a given spatial gradient (∇B). The magnetic torque is also dependent on the demagnetizing factors $(N_n - N_t)$, which cannot exceed 0.5[1].

$$M_s V = \frac{F_{mag}\mu_o}{\nabla B} \qquad \tau_{mag} = \frac{M_S F_{mag}}{2(\nabla B)}(N_n - N_t)$$

Since M_s is not known for most devices, two conservative upper-bound equations (Tier 1 and Tier 2) may be used to estimate the magnetic torque. Tier 1 magnetic torque (τ'_{mag}) can be calculated using a conservative magnetic saturation value for iron of 2.2 T. Tier 2 magnetic torque (τ''_{mag}) can be calculated using the largest magnetic saturation value of the materials within the implant ($M_{s,max}$), if known.

$$\tau'_{mag} = \frac{2.2\, F_{mag}}{4(\nabla B)} \qquad \tau''_{mag} = \frac{M_{s,max}\, F_{mag}}{4(\nabla B)}$$

Tier 1 magnetic torque and Tier 2 magnetic torque were computed and compared to the measured magnetic torque and gravity torque for four different devices.

Results:

Implant Type	τ_{meas} (mN·m)	τ''_{mag} (mN·m)	τ'_{mag} (mN·m)	$\tau_{gravity}$ (mN·m)
Pacemaker 1	1.91	4.9	17.9	18.8
Pacemaker 2	2.83	8.8	32.2	13.7
ICD 1	25.8	43.7	160.2	73.0
ICD 2	26.6	39.2	143.7	71.9

Discussion: For the 4 devices tested, $\tau_{meas} < \tau''_{mag} < \tau_{gravity}$. This demonstrates that, for these devices, a Tier 2 estimate is worst case, and that this method may be useful in alleviating the need to measure the magnetic torque per ASTM F2213. In addition, for pacemaker 1, $\tau_{meas} < \tau'_{mag} < \tau_{gravity}$. This demonstrates that a Tier 1 approach may also be useful for devices.

Conclusion: For some devices, torque testing per ASTM F2213 for MR conditional safety assessment may not be necessary, since a conservative magnetic torque value may be calculated using the measured magnetically induced force per ASTM F2052 and the physical properties of the device materials.

References:

1. Nyenhuis et. al, MRI and Implanted Medical Devices: Basic Interactions with an Emphasis on Heating, IEEE T-DMR 5(3), 467-80