Improved magnetically induced torque measurement for MRI safety testing

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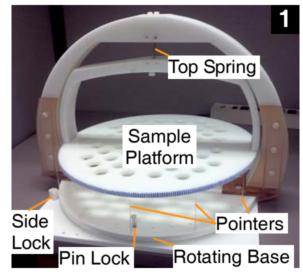
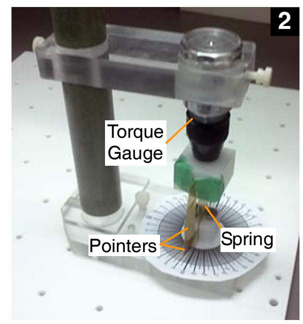
Target Audience Engineers and physicists developing implants and other devices for MR environments.

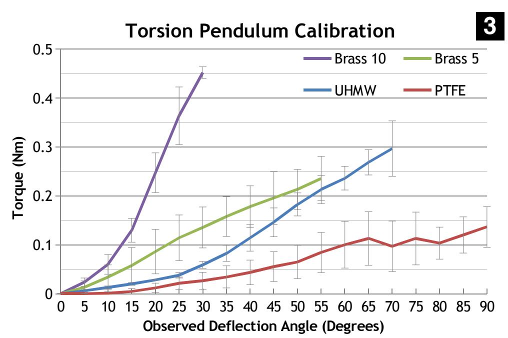
Purpose When evaluating the MRI safety of an object, it is important to measure torque induced by the static magnetic field. Published reports of such measurements are often qualitative[1], despite ASTM standard F2213-06[2] which prescribes a quantitative measurement method using a specified torsional pendulum apparatus. In the present work, practical improvements were made to this pendulum design, including a calibration procedure. The resulting apparatus has increased capacity and simplified construction, and its accuracy has been characterized. Example usage of the pendulum is also shown to assess the torque on a prototype tablet device for fMRI[3].





Methods As in ASTM standard F2213-06, the improved design (Fig. 1) includes a sample platform suspended by upper and lower flat torsion springs within a sturdy support frame, such that the sample platform's movement is restricted to rotation about the axis of the torsion springs. Notable differences from F2213-06 include: a) the support frame is mounted on a rotating base fixed to the patient table, eliminating the large turning knob and gear system; b) pin and side locks at 10º increments of the rotating base stabilize the support frame at each required measurement location; c) both the support frame and the sample platform frame are single, sturdy arches, to reduce obstructions and maximize the usable sample volume within a 60-cm diameter magnet bore; and d) torsion springs are secured in mounting blocks using thumbscrews, to ease spring-swapping. All parts except the springs were made from rigid plastics. Springs were cut from commonly available sheets of brass (alloy 260) with thicknesses 0.010” (0.25 mm, “Brass-10”) and 0.005” (0.13 mm, “Brass-5”), UHMW plastic with thickness 0.025” (0.64 mm), and PTFE plastic with thickness 0.010” (0.25 mm). According to F2213-06, torque induced on an item fixed to the sample platform is the product of the spring constant and the deflection angle relative to the zero-torque angle established outside the MR environment. However, rather than rely on published spring constant data, which may not be available or reliable for our particular samples, a bench calibration to relate rotation angle to torque was performed using a commercial torque gauge (ATG36Z, Tohnichi Mfg.) mounted on a test stand (Fig. 2). Six samples of each spring material were cut and mounted identically to the springs for use in the pendulum. A protractor and pointers taped to the sides of the mounting blocks were used to measure the angle between the spring's top and bottom. With the top mount suspended by the torque gauge, the bottom mount was manually rotated in 5º steps relative to the top mount until elastic behavior transitioned to non-recoverable yielding, while recording the torque on the gauge at each step. Torque values were averaged and multiplied by 2 to account for the 2 identical springs in the pendulum apparatus.

The example torque measurement of the tablet device was performed on a 3 T MRI system (MR750, GE Healthcare). The Brass-10 spring was chosen so that a 1º deflection measured using the degree markings on the circumference of the sample platform would indicate torque of 0.005 Nm. As required by F2213-06, this is less than 1/10 the worst case gravity torque given the mass and size of the tablet (1029 g × 32 cm long = 3.229 Nm) and its stylus (42 g × 15 cm long = 0.062 Nm). The patient table was undocked and moved outside the magnet room, where the apparatus was screwed to the table and the tablet was strapped to the sample platform using plastic ties. The zero-torque angle was marked on the edge of the sample platform with tape at each of the pointers projecting up from the rotating base. The table was then moved into the magnet room, and the apparatus was positioned at isocentre. Torque was measured at each 10º increment of the rotating base by noting any rotation of the sample platform from the zero-torque angle. The same procedure was repeated for three orthogonal orientations of the tablet and stylus.



Results Calibration data for each spring type (assuming 2 identical springs) are plotted in Fig. 3 (error bars are ±standard deviation). The tablet and stylus did not encounter any detectable torque using the Brass-10 spring, i.e. < 1º rotation, which is less than their worst case gravity torques. Therefore, the tablet and stylus pass the criteria for F2213-06 at 3 T.

Discussion Figure 3 shows that the torsion springs exhibit nonlinear elastic behavior. Thus, torque calculations that rely on published or measured elastic moduli for the spring materials are inadvisable. Instead, a calibration and “look-up table” procedure provides accuracy up to the limits of the reference torque gauge, subject to spring variation which is minimized by carefully preparing and mounting springs from a single large sheet of material. The new torque measurement apparatus is suitable for testing a wide range of items, including relatively large devices like the tablet which nearly spans the enlarged sample platform. In this example, no torque was detected on the tablet, but the quantitative nature of this method provides clear evidence of passing F2213-06. Future refinement and validation of the apparatus is also planned, particularly to monitor torque in real time. This will enable study of time-varying currents in medical devices, and the effects of moving devices through a magnetic gradient.

Conclusion An improved torque measurement apparatus for MRI safety testing was developed. The new apparatus facilitates quantitative torque measurement as part of medical device development.

References 1. Shellock FG. Biomedical Implants and Devices: Assessment of Magnetic Field Interactions With a 3.0-Tesla MR System. J Magn Reson Imaging 2002;16:721-732. 2. ASTM F2213-06. Standard Test Method for Measurement of Magnetically Induced Torque on Medical Devices in the Magnetic Resonance Environment. West Conshohocken, PA: ASTM International; 2006. 3. Tam F, Churchill NW, Strother SC, Graham SJ. A New Tablet for Writing and Drawing During Functional MRI. Hum Brain Mapp 2011;32:240-248.