**The Challenge:** To improve and validate a method of measuring magnetically induced torque, for MRI compliance testing and research.

- Published reports on MRI safety often use qualitative ratings of torque
despite the quantitative measurement prescribed by the ASTM F2213-06 standard.
- Some research questions benefit from precise quantification, e.g. empirical validation of electromagnetic simulations.

**Our Solution:** An improved torque measurement apparatus based on the torsional pendulum of F2213-06, with additional calibration and validation methods.

**Demonstration:** Safety testing of an existing tablet device used in fMRI applications and a ferromagnetic test object.

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### Methods

#### Improved torsion pendulum

- A sample platform is suspended within a sturdy support frame by identical upper and lower torsion springs (Fig. 1).
- Notable differences from F2213-06:
  - Mechanically simpler: The support frame is mounted on a rotating base fixed to the MR patient table; no gears.
  - Simple pin and side locking mechanisms for extra stability of the rotating base at 10° intervals.
  - Frame constructed from single, sturdy arches, to reduce obstructions and maximize the usable sample volume.
- Torsion springs are secured in swappable mounting blocks.
- All parts were made from rigid plastics (mostly acetal), except the springs.

#### Torsion spring selection

- Realistically, empirical testing is required to relate deflection angle to torque.
- In F2213-06, torque is the product of the spring constant and the deflection angle, which assumes an ideal, linear spring (and ideal pendulum apparatus), and the availability and reliability of spring material data for particular samples.
- To enable selection of appropriate springs for a given measurement, springs cut from sheets of 4 commonly available materials were characterized:
  - "Brass-10": Brass (alloy 260), 0.010” (0.25 mm) thick
  - "Brass-5": Brass (alloy 260), 0.005” (0.13 mm) thick
  - UHMW: Ultra high molecular weight polyethylene, 0.025” (0.64 mm) thick
  - PTFE: Polytetrafluoroethylene, 0.010” (0.25 mm) thick
- A torque gauge (ATG36Z, Tohnichi Mfg.) mounted on a test stand (Fig. 2) was used to measure 6 samples of each spring material:
  - With the top spring mount suspended by the torque gauge, the bottom spring mount was manually rotated.
  - Pointers indicated the angle between the top and bottom spring mounts on a protractor.
  - The torque on the gauge was recorded at each 5° step, stopping when the spring's elastic behaviour transitioned to non-recoverable yielding.
- Torque values were averaged and multiplied by 2 to account for 2 identical springs in the pendulum apparatus.

#### Torsion pendulum calibration

- A linear force gauge (T-50G-TC, Ametek, Inc.) was pushed against the sample platform arch, rotating the platform.
- Torque (tangential force x radius) was recorded at every degree of deflection up to the limit of the gauge.

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### Torque Measurement

- The Brass-10 spring was chosen so that 1° deflection indicates 0.004 Nm.
- This is less than 1/10 the worst-case gravity torque for the tablet (3.229 Nm) and the test object (0.122 Nm).
- The tablet and test object (Fig. 3) were tested with a procedure similar to F2213-06:
  - Outside the magnet room, the pendulum was screwed to the patient table, the object was strapped to the sample platform, and the zero-torque position of the sample platform was marked with tape.
  - The table was moved into the magnet room, and the pendulum positioned at isocentre.
  - The deflection angle of the sample platform was noted at every 10° increment of the rotating base.
  - The procedure was repeated for three orthogonal orientations of the object.
- The maximum deflection angle was converted to torque using spline interpolation of the torsion pendulum calibration data.

### Results

- Fig. 4 shows torque as a function of deflection angle for the 4 spring types, plus calibration data for the torsion pendulum with Brass-10 springs.
- The tablet did not encounter any detectable torque (< 1° deflection): PASS
- The test object had a maximum deflection of 9.5° (0.137 Nm): FAIL (> 0.122 Nm)

### Discussion

- Torque calculations relying on spring constants are inadvisable. Instead, use a force gauge to calibrate the apparatus.
  - This accounts for both nonlinear elastic behaviour of the springs themselves and any nonideal behaviour of the torsion pendulum apparatus.
  - Accuracy is limited by the accuracy of the force gauge.
  - The mismatch between measurements of the spring alone and installed in the pendulum suggests room for improving the apparatus in the future, if necessary.
- The improved torsion pendulum is suitable for testing a wide range of items, including larger devices like the tablet.
  - The mechanical improvements make the apparatus easier to build and use, and the addition of calibration and quality assessment methods augment F2213-06.
  - The apparatus is usable not only for compliance testing, but also for other research applications requiring quantitative torque measurement.
- Future refinements are planned, e.g. video recording for remote/real-time torque monitoring to study time-varying currents in medical devices; characterization of additional spring materials including phosphor bronze and polyurethane.

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**References:**

**Acknowledgements:** Heart and Stroke Foundation of Ontario Centre for Stroke Recovery; Canadian Cancer Society.

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