Uncertainty Analysis of Torque Measurement Methods Described in ASTM F2213-17

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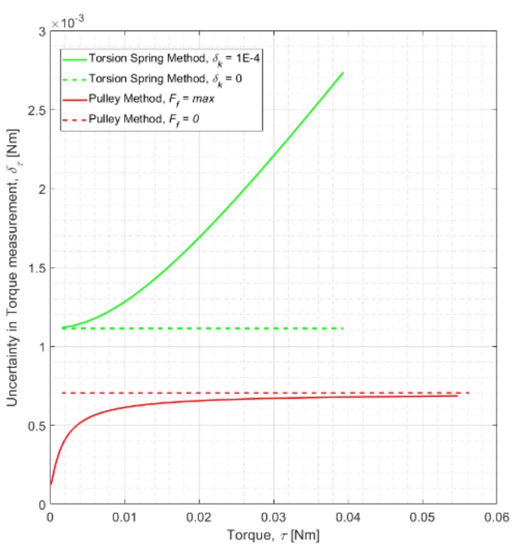
Introduction: The number of people with permanent or semi-permanent medical implants has seen annual growth in parallel with the growth of MRI as a diagnostic tool not only in Canada and abroad. There is a need to know whether patients with medical implants that cannot be readily removed, can receive a scan without complications, one of which is the possibility of torque on the implant. The current test standard for measuring magnetically induced torque in medical implants is the ASTM F2213-17 [1] which lists five methods. Three of the methods are pass/fail criteria. The remaining two methods, the ones under consideration in this abstract, are the 'torsional spring' and the 'pulley' methods, which aim to measure a quantitative torque value. The purpose of this work is to identify and compare the measurement uncertainties in the methods published by ASTM International, and thereby aid in the selection of the appropriate method for any device or system.

Methods: In the torsional spring method, there are errors in reading the angular deflection, likely the dominant source of error, and in calibrating the torsion spring constant. In the pulley method, there are errors in the force sensor and measurement of the apparatus radius. There is also an error in the torque required to overcome static friction. To find the error in static friction, measurements are made using the pulley method apparatus. A lightweight thread was extended from the apparatus and placed over a secondary pulley and attached to a hanging mass. The surface was divided into 30° sections. The mass suspended was incrementally increased until the weight was enough to set each section of the surface in motion. The method of changing the mass was to place staples into a small basket. Staples were chosen because individually, the mass is insignificant, but multiple staples have a noticeable change in torque in a tangible quantity allowing for reproducibility. For a function, x, such that $x = f(u_1, u_2, \ldots, u_n)$, the uncertainty, δ_x, based on known sources of error is propagated by, $\delta_x^2 = \sum_{i=1}^{n} \delta_{u_i}^2 \left(\frac{\partial x}{\partial u_i}\right)^2$. This equation is true when all independent variables are uncorrelated. An expression for measurement uncertainty of each method can be calculated and propagated to see how uncertainty changes with torque.

Results: The standard deviation of masses required to set the surface in motion came to 1.394 g or a torque of 0.693 mNm. $\delta_{F_S} = 0.693$ mNm was used in the error propagation of torque and measurement uncertainty starting from the smallest observed torque, 1.574 mNm, as shown in **Figure 1**. The calibration report of the force sensor used listed a capacity of 1.11 N and an uncertainty of 1.668E-3 N. Measurements using a digital caliper yielded a radius apparatus of 50.72 ± 0.01 mm. The torsional spring method required a spring constant capable of measuring 1° intervals which yielded $\delta_\theta = 0.5°$. For $\tau = 1.574$ mNm, $k = 1.574$ mNm with an arbitrarily chosen δ_k.



Conclusions: As was anticipated, the dominant source of error in the torsional spring method was the instrument uncertainty of the protractor. The dominant source of error in the pulley method was the error due to static friction. For comparable measurements of torque, the pulley method, while considering all sources of error, fared better than the torsion spring method.

References:

[1] ASTM International, "F2213-17 Standard Test Method for Measurement of Magnetically Induced Torque on Medical Devices in the Magnetic Resonance Environment"

Figure 1: Propagation of errors for ASTM methods, starting from 1.574 mNm until a deflection of 25° for the torsional spring method and 1.11 N force sensor reading for the pulley method.