Modelling Static Field Induced Torque on Simplified Medical Devices

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INTRODUCTION: The most recent test standard published by ASTM International for assessing the MR compatibility of medical devices, specifically static field induced torque, outlined five experimental test methods as an update to the previous edition with only one method [1,2]. As of Dec 2019, there is not an internationally recognized method for assessing torque by computational means. In the development of systematic and efficient testing of medical device safety, numerical methods based on the finite element method (FEM) are a possible tool that could be used to model the torque induced on devices placed in the static field environment of an MR scanner. The torque induced on stainless-steel (SS) grades 304 and 316 cylindrical rods were measured and compared to the results from a torque simulation created in COMSOL (COMSOL Inc., Sweden), an FEM solver.

METHODS: Sixteen rods (SS304 and 306, $d = 0.64$ and 1.27 cm, and $l = 3, 5, 7,$ and 9 cm) were measured on a 3 T scanner using the *Pulley Method* from ASTM F2213-17. Measured values were compared with simulated values obtained from COMSOL. A cubic simulation domain was created into which, cylinders of dimensions matching the machined SS rods were placed. The magnetic susceptibility, χ, defined the properties of the cylinders while all other domains were defined as air. A 3 T external field was applied, and the ASTM experimental procedure was simulated. All objects were discretized with tetrahedra with dV being the size of each element. Two physics solvers, *Magnetic Fields, No Current* and *PDE Coefficient*, were used to solve for $\mathbf{B}$ and $\nabla\mathbf{B}$ respectively. The peak torque experienced by each simulated cylinder was found by summing the torque on each individual element at a distance, $\mathbf{r}$, from the center of the cylinder given that $\boldsymbol{\tau} = \mathbf{F} \times \mathbf{r}$ and $\mathbf{F} = \frac{\chi dV}{\mu_0(1+\chi)}(\mathbf{B} \cdot \nabla)\mathbf{B}$.

RESULTS: The experimentally measured and simulated torques of each rod was tabulated with the percentage difference calculated using measured values as truth (**Fig. 1**).

	Length	Tests [mNm]	Sims [mNm]	% diff
SS316 *d* **= 1.27 cm** χ **= 5026 ± 34 ppm**	3 cm	0.133 ± 0.018	0.134	0.752
	5 cm	0.307 ± 0.018	0.301	1.954
	7 cm	0.444 ± 0.019	0.452	1.802
	9 cm	0.614 ± 0.021	0.612	0.326
SS304 *d* **= 1.27 cm** χ **= 12246 ± 207 ppm**	3 cm	0.772 ± 0.016	0.789	2.202
	5 cm	1.710 ± 0.027	1.788	4.561
	7 cm	2.787 ± 0.040	2.677	3.947
	9 cm	3.728 ± 0.052	3.643	2.280
SS316 *d* **= 0.64 cm** χ **= 5501 ± 79 ppm**	3 cm	0.052 ± 0.002	0.053	1.923
	5 cm	0.105 ± 0.004	0.103	1.905
	7 cm	0.145 ± 0.005	0.141	2.759
	9 cm	0.168 ± 0.006	0.175	4.167
SS304 *d* **= 0.64 cm** χ **= 12542 ± 128 ppm**	3 cm	0.272 ± 0.008	0.274	0.735
	5 cm	0.515 ± 0.012	0.538	4.466
	7 cm	0.739 ± 0.016	0.732	0.947
	9 cm	0.936 ± 0.018	0.912	2.564

Fig. 1: The simulated torques were compared to measurement by percent difference and gives a sense of the numerical accuracy.

CONCLUSIONS: The experimental and numerical torque peaks appear to increase linearly with length of the rod. The percent difference between the experimental and numerical values were less than 5%. The susceptibilities calculated all lie in the range expected for the stainless-steel materials often reported as between 1000 to 20000 ppm with SS316 more precisely known to be between 3520 to 6700 ppm. It is important to note that this method still requires validation using a material with a known magnetic susceptibility. However, internally the simulation is seen to be self-consistent and given this self-consistency, FEM models would provide an effective tool in efficiently and systematically assessing medical devices. With further validation, the application of numerical methods to device testing could minimize the number of measurements required. Rather than testing every configuration within a group of devices, conservative limits can be established on the group as a whole via laboratory measurements on the computationally identified worst case. Although this study just the preliminary step, further studies on models with greater geometric complexity may reveal FEM to be an effective tool in assessing the MR compatibility, in regard to static field induced torque, of whole product lines of medical devices.

[1] ASTM F2213-17 (2017) [2] Woods, T. O. (2007) *J Magn Reson Imaging*, 26, 1186–1189 [3] Nyenhuis, J. A. et al. (2005) *IEEE T Device Mat Re*, 5(3), 467–480 [4] Schenck, J. F. (1996). *J Med Phys*, 23(6), 815–850.