A NOVEL QUANTITATIVE METHOD FOR MEASURING THE TORQUE ACTING ON CARDIOVASCULAR IMPLANTABLE DEVICES IN NMR SCANNERS

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Introduction The use of MR techniques is widespread in the clinical field including diagnosis and monitoring of pathologies of heart and large vessels. The question arises whether cardiovascular implants such as mechanical heart valve prostheses can withstand the static field exposure of the last generations' systems. Among the possible interactions between cardiovascular devices and the magnetic field, attraction force and torque are the most relevant for safety considerations. A new method for the quantitative determination of the torque is here proposed and validated.

Theory The torque exerted on the valve causes the wire to rotate by an angle α, corresponding to the equilibrium between the torque due to the magnetic field and the reaction torque of the wire. Since the device is in contact with the wire in correspondence to a single point, ideally, the wire itself can be thought of as being decomposed in two parts (whose length is denoted as l_1 and l_2 respectively), both rotated by α. Then the torque tending to move the valve back to the initial angle (α_0) is given by $T=T_1+T_2$, where $T_1= (\alpha-\alpha_0)JG/l_1$ and $T_2= (\alpha-\alpha_0)JG/l_2$, being J the polar moment of inertia of the wire segment (defined as $J = \pi/2 * r^4$, where r is the wire radius), and G is the shear modulus of copper.

Methods
The device was suspended in the magnetic field by means of a torsion balance. Copper wires were used as the elastic element in the balance. The wire was wound twice at the hinges of bileaflet heart valve's housing ring, and the two free ends were firmly attached to a cylindrical holder as shown in Fig. 1. The wire was tightly pulled, so that only the orientation of the valve (i.e. the angle between the valve plane and the scanner's axis) was allowed to vary during the experiment. A small mirror was positioned on the valve sewing ring, perpendicular to the valve plane. The cylindrical holder was then placed on a MRI cradle at the magnet centre. The deflection angle was measured by projecting a laser beam (He-Ne laser, 35 mW CW), parallel to the magnet axis, on the valve-mounted mirror, and by recording the longitudinal position (x) of the spot reflected by the latter on a graduate scale sited on the inner side of the MRI cradle. The relationship between x and α is straightforward. Measurements were performed by the small bore system Varian Inova, 200/183 operating at 4.7 T. Two set-ups were adopted, one with D=0.18 mm, and the other with D=0.30 mm, while maintaining the wire lengths l_1 and l_2 fixed. Thus, at a given value of the torque T, inversely proportional deflection angles were observed in the two cases: $\Delta\alpha_{0.30}/\Delta\alpha_{0.18} = J_{0.18}/J_{0.30} = (0.18/0.30)^4$, where $\Delta\alpha= \alpha-\alpha_0$ is the deflection angle, and the subscript of each quantity denotes the relative wire diameter, in mm.

Results
The method was tested on a bileaflet mechanical heart valve. Factors affecting the precision of the measurements are α_0, l_1 and l_2 and wire diameter. The theoretical error calculated for the largest diameter (the worst case) as a function of α_0 was always less than $2.2 * 10^{-5}$ N*m. Fig. 2 reports the theoretical error for the smallest and largest diameter considered (dotted and solid line, respectively). In our case (α < 15°) the experimental error was always < $0.5\ 10^{-5}$ N*m. The torque values measured for the 0.18 and 0.30 mm wire diameters were 2.3 ± 0.2 and $2.6 \pm 0.9\ 10^{-5}$ N*m, respectively. The difference was within the experimental error. The measured torques corresponded to equivalent forces (F_{eq} = T/TAD, TAD = tissue annulus diameter) three order of magnitude smaller than the force exerted by the beating heart (i.e. approximately 7.2 N).

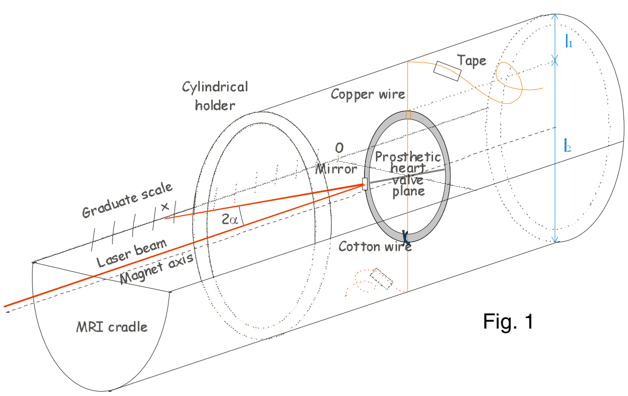

Fig. 1

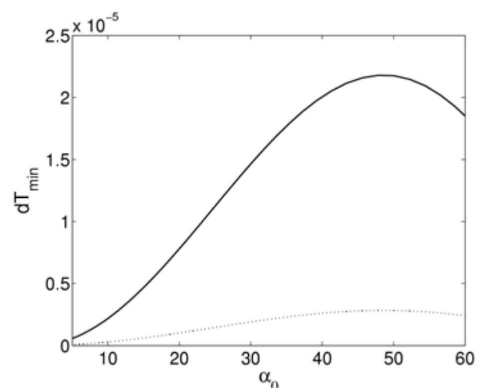

Fig. 2

Discussion
To the best of our knowledge this is the first quantitative assessment of the torque exerted by a static magnetic field on an implantable cardiovascular device such as a cardiac prosthetic valve. Advantages of the method are high precision (two order of magnitude better than reported by other[1] , high accuracy (difference between torques measured using two different wire diameters was $0.3\ 10^{-5}$ N*m), easiness of implementation, low cost, and possibility of application also to small devices such as stents.

Conclusions
The interaction between static magnetic fields and mechanical prostheses is quantifiable by the torque value measured in a torsion balance, independently on the wire diameter. The measured torque provided clear indication of safety up to 4.7 T for the here considered heart valve prosthesis. This approach will be extended to different valve types.

References
1. Shellock FG, J Magn Reson Imaging 12, 214, 2000.