Title: Characterization of a novel highly porous 3D printed metal structure in MRI

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Structured Abstract:

Introduction: MRI is useful in diagnosing the two most common causes for revision of orthopedic implants, infection and aseptic loosening. However, the difference in magnetic susceptibility between metals and tissue gives rise to substantial magnetic field inhomogeneity, leading to image artifacts that obscure diagnosis and limit quantitative imaging. Magnetic susceptibility is well understood and readily simulated, but little work has been done to explore the effect of porosity on metal artifacts. The development of metal 3D printing has made it possible to design and build a highly porous repeating gyroid cell structure that fits within a contour of any desired shape. This study explores the hypothesis that increasing the gyroid's porosity will reduce effective susceptibility, leading to smaller artifacts and decreased field inhomogeneity, increasing the feasibility of MRI around porous implants compared to traditional solid metal.

Methods: To measure the effects of varying porosity, 5 gyroids conforming to a cylinder with 17 mm diameter and 40 mm length were designed by repeating a 6 mm unit cell and varying thickness between 0.2 mm – 0.8 mm. The resulting designs (60%, 70%, 80%, 85% and 90% porosity) and a solid cylinder (0% porosity) were 3D printed in titanium (Ti-6Al-4V, $\chi = 182$ ppm). Signal dropout volume was measured through binary thresholding while an estimation of effective susceptibility was achieved by comparing experimentally acquired field maps against simulated field maps of a cylinder assigned variable susceptibility values. Field maps were calculated from the difference in phase accumulation between two gradient-echo scans at 3T (8-channel head coil; 256x128x128; 1 mm isotropic voxels; TE = 3, 3.5 ms; TR = 15 ms; 15° flip angle) with the early echo magnitude image used for signal dropout analysis.

Results: Weighing the 5 gyroids shows that their masses were linear with their nominal porosity ($R^2 = 0.99$). Signal dropout volume is also highly linear ($R^2 = 0.99$) showing decreasing artifact size with increasing porosity. The simulations were calculated at 0.5 mm isotropic voxel size for susceptibility values between 1-200 ppm and resampled to match the 1 mm scanned voxel size. The scanned field maps were matched with these simulations to estimate their susceptibility.

Discussion: We have shown qualitative and quantitative evidence that susceptibility induced metal artifact is reduced with increased porosity. Showing this artifact reduction using a gradient echo sequence adds further value as spin echo is overwhelmingly used for imaging around metals as it performs better in the presence of field inhomogeneity. Further work exploring potential applications of the gyroid will benefit from MR based analysis, particularly using gradient echo based quantitative imaging.