Empirical and Computed B_0 Perturbations Induced by Metallic Implants

K. M. Koch[1], and R. S. Hinks[1]

[1]Applied Science Laboratory, GE Healthcare, Waukesha, WI, United States

Introduction: The material compositions of most prosthetic implants induce very large spatial perturbations to the B_0 magnetic field. Identifying the geometry and magnitude of such field perturbations can assist in developing methods to improve MR imaging in the vicinity of metal implants. Existing conventional MR-based field mapping methods cannot produce accurate field maps in the near vicinity of most implants. Here, it is demonstrated that previously published and studied FFT-based rapid computations of B_0 field perturbations can be used to a) estimate the previously unpublished magnetic susceptibility of a commonly utilized cobalt-chromium alloy, and b) accurately determine implant-induced B_0 distribution of a cobalt-chromium prosthetic component. A novel B_0 mapping procedure is also introduced, whereby accurate far off-resonance contour field maps can be measured using MR techniques.

Methods: A first-order approximation to the B_0 field perturbation induced by an input 3D magnetic susceptibility distribution satisfies the relation

$$\Delta B_0(r) = FFT^{-1}\left[B_0\left(\frac{1}{3}-\frac{k_z^{\,2}}{|k|^2}\right)FFT\ [\chi(r)]\right],$$

where B_0 is the applied static field strength, **k** is the Fourier-space coordinate $\chi(r)$ is the magnetic susceptibility distribution and $\Delta B_0(r)$ is the perturbed field distribution [1][2][3]. The physical approximation utilized in the method's derivation requires the amplitude of object-induced magnetic fields to remain far less than the applied static magnetic field. Here it is demonstrated that this condition remains satisfied for MR-compatible [4] metallic implants where induced field-offsets of order 10 kHz remain negligible compared to applied B_0 fields of order 100 MHz.

Imaging experiments were performed on a GE Signa 1.5T scanner. Computations were performed on a Dell Precision 690 workstation equipped with quad 180 GHz Xenon processors and 16 GB of RAM. 3D B_0 distributions for computational grids of 256x256x128 can be evaluated in less than 10 seconds using this hardware configuration. Field maps (24 cm field of view) were collected near a Zimmer© (Warsaw, IN) cobalt-chromium (CoCr) hip-ball prosthesis centrally embedded in a 1cm thick water phantom of radius 22.5cm (Figure 1A).

A non-slice-selective coronal spin-echo field-map was acquired with refocusing pulse bandwidths of 1kHz, thus eliminating spins at resonance offsets greater than +/-500 Hz from the acquisition. As seen in Figure 1C, this process resulted in an accurate, but limited map of the implant-induced B_0 distribution. A CAD model of the implant was then rasterized into a 3D array for input into a Matlab ΔB_0 solver based on the above equation. An estimate of the effective magnetic susceptibility for the CoCr material was determined by iterating the computation until the difference between the computation and measured field map was minimized over the active signal regions in the limited field map.

Far off-resonance contour B_0 maps were assembled from multiple 3D FSE images acquired at different central transmit and detection frequency offsets. Non-selective refocusing pulses were utilized with frequency offsets of 0.5kHz per image. Thirty-three images were acquired, thus spanning resonance offsets of +/-8.25 kHz. Each reconstructed image contained signal over different 3D volumes. Contour field maps were constructed by identifying the image with maximum intensity for each pixel and then assigning B_0 value corresponding to the resonance offset utilized in that image's acquisition. The result was an accurate contour field map with 0.5 kHz bins. The spatial resolution of these B0 maps is determined by local induced field gradients. Therefore, the map has greater spatial resolution in the immediate vicinity of the implant and reduced resolution further from the implant.

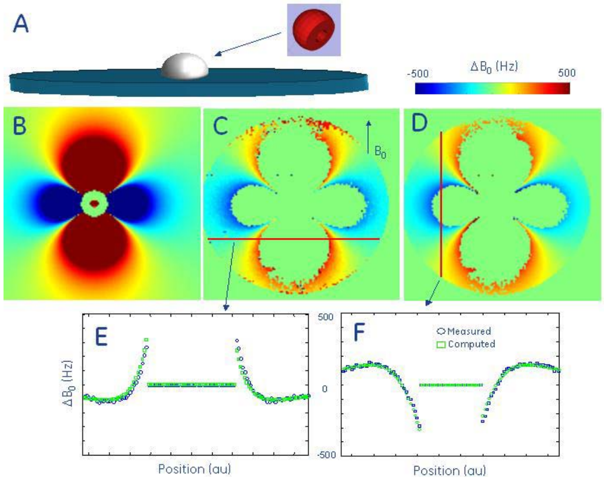

Figure 1: A) Phantom setup including CAD model of implant used for computational input, B) computed ΔB_0 distribution for CoCr susceptibility of 900 ppm, C) measured limited spatial field map, D) computational map over limited map's domain, E-F) indicated field traces

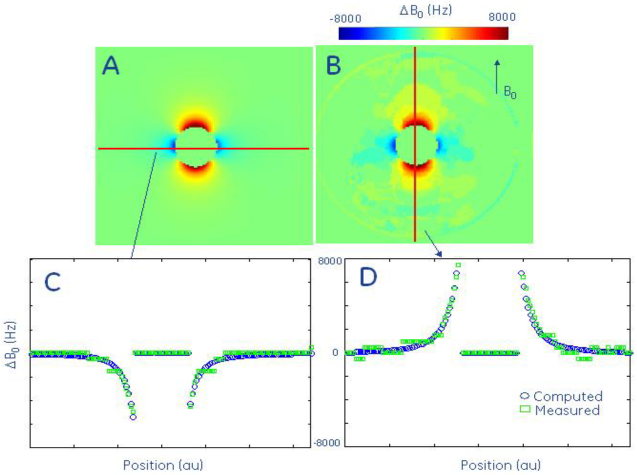

Figure 2: A) computed ΔB_0 distribution, B) measured composite contour field map, C-D) indicated field traces

Results and Discussion: The simulated and empirical results shown here enabled the determination the hip-ball prosthesis (CorCr) magnetic susceptibility, which was found to be roughly 900 ppm. This is about 5 times the literature value of magnetic susceptibility for titanium [4], and explains the increased severity of MR image artifacts near cobalt-chromium as compared to titanium implants. Using this susceptibility value, the agreement of the computation and measurement in low-resonance offset (< |500| Hz) regions is clear in both the field maps and traces in Figure 1. Figure 2 shows the computational map and measured composite contour B_0 map (0.5 kHz bins). The agreement between the measurement and computation at far-off resonance frequencies is demonstrated here. In the immediate vicinity of the implant, at ΔB_0 offsets of 8kHz the computation is closely matched with the empirically measured field distribution. These results show that high spatial resolution ΔB_0 distributions induced by MR-compatible metallic implants can accurately be computed using rapid FFT-based computed solutions and that far-off resonance B0 maps of limited spatial resolution can be measured with MR methods. Such capabilities may have a wide variety of potential utilities (both diagnostic and corrective) in developing and executing procedures for mitigation of MR artifacts near metal implants.

[1] R. Salomir et al, Concepts in Magn. Reson B., **19B**, 26-34, (2003)
[2] JP Marques, R. Bowtell, Concepts in Magn. Reson. B., **25B**, 65-78 (2005)
[3] KM Koch et al, Phys. Med. Biol, **52**, 6381-6402 (2006)
[4] J Schenck, Med Phys., **23**, 815-850 (1996)