Hybrid structure design for implants: dramatic reduction of the metal artifacts

Toru Yamamoto[1], Yanhui Gao[2], and Kazuhiro Muramatsu[2]
[1]Faculty of Health Sciences, Hokkaido University, Sapporo, Hokkaido, Japan, [2]Department of Electrical and Electronic Engineering, Saga University, Saga, Japan

TARGT AUDIENCE

MR Physicist, MR Engineer, MR Technologist

PURPOSE

MR artifacts caused by implants are hindering proper diagnosis. Lowering the susceptibility of the material has been being developed, but even titanium (Ti) is not enough for several diagnoses. To reduce these metal artifacts to a small area to enable diagnosis, we propose a new structural design of implants with hybrid of paramagnetic outer shell and diamagnetic inner core.

METHODS

We simulated a magnetic field distortion of a rectangular implant (4 mm × 4 mm × 20 mm) which mimics an intervertebral spacer. The linear magnetostatic simulation of one-eighth of the whole implant was performed due to symmetry by using the magnetic scalar potential Ω method with the 1st-order hexahedral finite element method FEM[1)]. In the simulation, the static magnetic field (1.5 T) of MRI was applied in the z direction and the three dimensional mapping of the magnetic field of the z component was obtained. The simulated implants were modeled with bulky structure of paramagnetic Ti and hybrid structure of outer shell (Ti) and inner core (diamagnetic graphite), and the volume susceptibility of the surrounding space was set at -9.0×10^{-6} in SI units of the water. The susceptibility of Ti was set at 160×10^{-6}. Although the susceptibility of graphite was reported as -220×10^{-6}, we set it at -106×10^{-6} taking into account the realistic filling factor of the graphite powder. For the simulation of the hybrid structure, the thickness of the outer shell was initially set at 1 mm and then the design of the inner core shape was iterated to reduce the magnetic field distortion. This structural iteration of the inner core shape was performed to minimize the volume where the magnetic field distortion was larger than 30 ppm with a criterion that the thickness of the outer shell must be greater than or equal to 0.5 mm. This structural criterion guarantees the mechanical requirement of fabrication.

RESULTS

The simulated results of the magnetic field distortion are shown in Fig. 1. The distortion of the bulky structure of Ti spread greatly, but that of the hybrid structure decreased dramatically. The distortion (larger than 30 ppm) of the optimum shape obtained by the iterative design was small enough to limit the area within 2 mm from the surface of the implant; this area becomes void in a normal SE imaging.

DISCUSSION

The structural design of hybrid combination of paramagnetic and diamagnetic materials effectively decreased the magnetic field distortion. In particular, optimization of the inner core design reduced the supposed void area within 2 mm from the surface of the implant. This 2-mm distance is one example of the allowable artifact size which enables the diagnosis of spinal cord of patients with a vertebral implant. Therefore, the hybrid design of the implants is promising to overcome the hindrance of diagnosis that is caused by artifacts due to present implants. The artifacts depend on the orientation of the implants to the magnetic field of MRI. However, the orientation of most of orthopedic implants during MRI examinations is almost the same for each type of implant. Correspondingly, an artifact of an orthopedic implant is also almost the same. Therefore, the hybrid design can be easily applied to orthopedic implants. Additionally, the hybrid design has a merit that biocompatible and mechanical requirements of implants can be kept by employing paramagnetic material like Ti of the present implants. The method of controlling the susceptibility of graphite should be investigated for manufacturing the implants that use our technique.

CONCLUSION

The hybrid structure of paramagnetic and diamagnetic materials reduces the metal artifact of the implant dramatically. This structural design would be applied to various orthopedic implants.

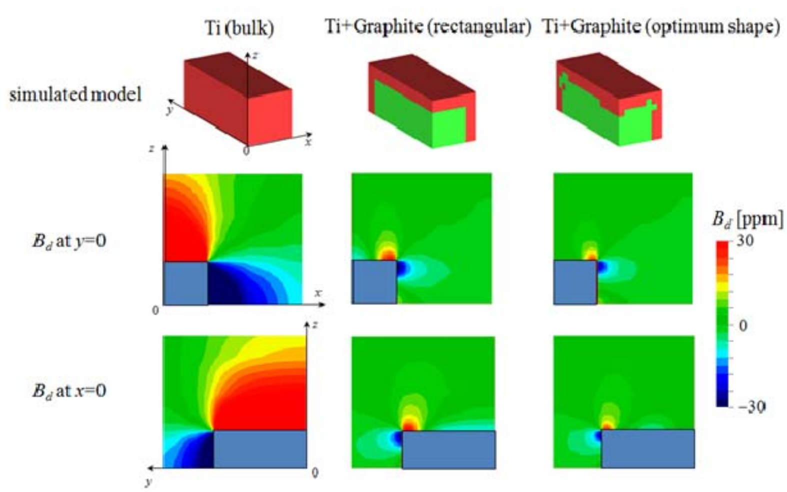

Figure 1. Simulated magnetic field distortion (*Bd*) around the implants. One-eighth (2 mm × 2 mm × 10 mm) of each rectangular implant was drawn. The direction of the magnetic field of MRI is defined as a z axis. Each implant was placed perpendicularly to the magnetic field.

REFERENCES

1. Gao Y, Muramatsu K, Kushibe A, Yamazaki K, Chiba A, Yamamoto T. Reduction of artifact of metallic implant in magnetic resonance imaging by combining paramagnetic and diamagnetic materials. J Appl Phys. 2010;107: 09B323-1 - 09B323-3.