NEW APPROACHES OF RF COIL AND GAMMA RAY RADIATION SHIELDING ASSEMBLY FOR SPECT/MRI SYSTEM

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Introduction

Most of the nuclear imaging systems require the use of a gamma (γ)-ray radiation shield to attenuate a stream of γ-rays so that only those traveling in a specified direction are allowed through and to absorb the scattered γ-rays from out of interest regions [1-2]. To meet those requirements, a γ-ray radiation shield is usually made out of lead (Pb) or some other high Z material such as titanium (Ti) or tungsten (W) but these materials cause B1 field distortion due to their ferromagnetism in an MR bore for a combined SPECT/MRI system. They also lead to not only a resonance frequency shift but also a drop in the quality (Q) factor because of their electrical conductivity when the γ-ray radiation shield is covered by the RF coil. Therefore, we have developed a new design to retain the tremendous potential of SPECT/MRI with high sensitivity and specificity and to minimize the interference between MRI and SPECT. In this work, we present a new assembly with RF coil and a γ-ray radiation shield to prevent MR image distortion and degradation of SNR as well as show the fact that our concept is more predominant than a conventional assembly through Q-factor variation.

Methods

In such as a conventional SPECT/MRI setup (Fig1 (a)), a cylindrical hollow shaped γ-ray radiation shield covers the RF coil while maintaining a certain distance to avoid losses in the SNR and B1 field inhomogeneity; on the contrary, SPECT spatial resolution is degraded when a SPECT detector is located at a farther position from the subject. Therefore, based the above-mentioned issues about RF coil and a γ-ray radiation shield, we propose an assembly such as shown in Fig1(b) for an RF coil which has three receive channels and a γ-ray radiation shield that is made of a specialized lead acrylic composite powder in order to reduce its conductivity. The composite radiation shield was based on lead powder suspended in acrylic plastic (thickness: 2.9mm) with a lead concentration capable of blocking 96.9% from 121 KeV peak photons of Co^{57} source. The proposed composite radiation shields have three pin-hole assemblies embeded which are positioned between the neighboring RF coil segments that are 120º apart (Fig1 (b)). On the cross sectional view of the designed composite radiation shields, they have funnel shaped cross sections on which CZT detectors could be seated, which would become a key to acquire high spatial resolution SPECT data by bringing the pinhole or parallel collimators close to the subject. Two identical hollow acrylic pipes (diameter: 50mm, lengths: 200mm) were prepared to build two different shaped RF coils that had 170mm length identically. One coil was a conventional high-pass type quadrature birdcage coil that has been used in previous studies and the other coil was the three-channel receive only coil that we propose in this paper. The birdcage coil consisted of 8 rungs made from copper tapes with a 3mm width and 40μm thickness.

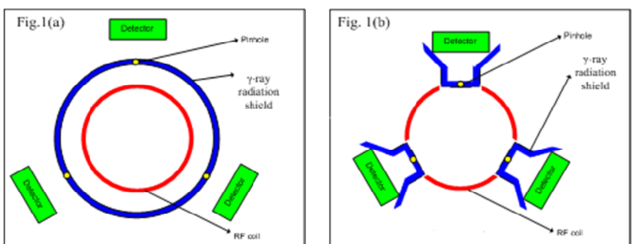

Figure 1. (a) Conventional assembly of a birdcage coil and detector module with a hollow cylindrical shaped γ-ray radiation shields. (b) Proposed assembly of the three-channel array coil and detector module with three γ-ray radiation shields designed to fit within the gaps between the neighboring RF segments.

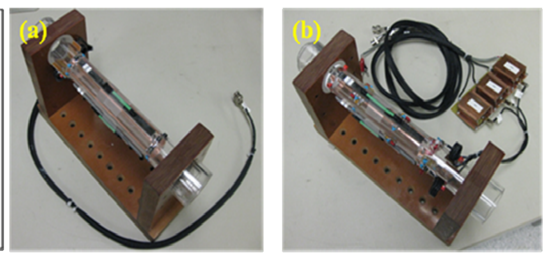

Figure 2. (a) Birdcage coil with 120° positioned γ-ray radiation shields. (b) Three-channel array coil with 120° positioned γ-ray radiation shields.

The received only array coil was made up of three rectangular shaped elements that were positioned at 120º apart around a hollow cylindrical acrylic pipe. The passive detuning method was utilized to decouple the array coil from the RF transmitter while high power RF energy was transmitting. Coupling between the neighboring segments was reduced using the inductive decoupling method [3]. Isolations among neighbor channels were -20.7dB, -21.1dB, -21.5dB separately. Three pieces of γ-ray radiation shields (width = 10 mm, length = 150mm) were made of composite lead. Another set of γ-ray radiation shields with the same dimensions but made of solid lead were also prepared to compare the performance difference between the two materials. The γ-ray radiation shields were located at the gaps between the RF coil elements of the three-channel array coil as shown in figure 1(b). For the experiments with the conventional birdcage coil the indentations were placed in geometrically identical positions (figure 1(a)). A 4395A network/Spectrum/Impedance analyzer (Agilent Technologies) was used to measure the Q factor and resonant frequency with and without the three γ-ray radiation shield plates attached on the RF coil.

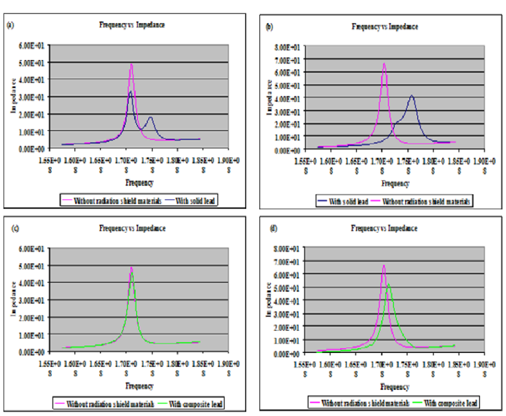

Figure 3. (a) The frequency spectrum for one (channel #1) of the three-channel array coil without (pink line)/with (dark blue) setting the solid lead plates on the three-channel array coil. (b) The frequency spectrum for the birdcage coil without (pink line)/with (dark blue) setting the solid lead plates on the birdcage coil. (c) The frequency spectrum for one (channel #1) of the three-channel array coil without (pink line)/with (green) setting the composite lead plates on the three-channel array coil. (d) The frequency spectrum for the birdcage coil without (pink line)/with (green) setting the composite lead plates on the birdcage coil.

Results

As expected, the solid lead γ-ray radiation shields positioned on both RF coils caused a frequency shift and Q-factor drop (figures 3a & 3b) as a result of their high conductivity. As shown in figure 3b, the frequency spectrum of the birdcage coil shifted and Q factor dropped considerably compared to the three-channel array coil. The resonance frequency shifted about 2~3MHz. A split in resonance frequency was also observed, which indicates increased mutual coupling due to the presence of the solid lead γ-ray radiation shields. While the solid leads caused a significant broadening and shift in the frequency spectrum, the proposed composite lead resulted in a negligible shift in the resonance frequency (±0.1MHz) when they were attached on either RF coil (figures 3c & 3d). However, the variation of the Q factor with and without the composite leads on the RF coils demonstrates the difference between the three-channel array coil and the birdcage coil with the phantom loading (three-channel array coil Q factor change = 5.7%, 5.8%, and 7.2%; birdcage coil Q factor change = 18.0%). Even though our proposed composite radiation shield was less conductive, a higher drop in Q factor was observed with the birdcage coil compared to the three-channel array coil.

Discussion and Conclusion

In this study, we reported on the successful implementation of an RF coil designed for an SPECT/MRI system that uses three γ-ray radiation shields. The new RF coil was compared with the conventional birdcage coil under the same settings. The composite lead γ-ray radiation shields positioned on the gap between the nearest neighbor coils minimized the loss of SNR and B1 uniformity in the MR images. An additional advantage of the proposed three-channel coil is that a pinhole or parallel collimator can be brought much closer to the object resulting in an improvement in spatial resolution or sensitivity in the SPECT images depending on the type of collimator used. We anticipate that our new assembly will be a feasible addition to multi-modality imaging technology for not only animal studies but also for the *in vivo* study of humans.

References [1] Azman S *et al.*, *IEEE NSS-MIC: 2311-17(2007).* [2] Chen S *et al.*, *IEEE NSS-MIC: 3250-55* (2007). [3] Nabeshima T et al., *U.S. patent*, 489,847 (1996).
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