Wireless Radio Frequency Coil for Magnetic Resonance Image of Knee Joint

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ABSTRACT

An inductively coupled wireless radio frequency (RF) coil has been developed to improve the quality in the magnetic resonance imaging. The wireless coils of a Helmholtz type and a birdcage type were manufactured, and the resonance frequency was tuned at 64 MHz. Several magnetic resonance images were taken on a phantom, on a rabbit's head and on a human knee joint with the RF coils. The signal to noise ratio (SNR) has been compared at the acquired images. The experimental results show that the SNR is improved with application of the inductive coupling between the RF coils.

Keywords: Biomeasurement, Magnetic Resonance Imaging, Radio Frequency Coil, Signal to Noise Ratio, Inductive Coupling

1. INTORDUCTION

Magnetic Resonance Imaging (MRI) is a computed tomography, which being used a nuclear magnetic resonance phenomenon [1]. It is useful tool for diagnostic medical imaging, since it is a non-invasive tool to study both anatomy and function of human body.

The radio frequency coils, known as RF (radio frequency) resonators or RF probes, are the key components in a magnetic resonance scanner [2]. They pick up the radio frequency waves which being radiated inside the human body in the strong static magnetic field. The RF coils have been studied to improve their capabilities by many researchers. Arrayed divided coils were designed to decrease noise in the Magnetic Resonance Image, for example, because noise increases with the size of the coil [3]. In the previous study, an Archimedean spiral coil for MRI was designed and the electric character was simulated [4, 5].

In the RF coil, an electric noise increases with its dimension, which decreases the signal to noise ratio (SNR). To maintain the quality of magnetic resonance images, several factors have been investigated in many trials.

The RF coils are classified into two types: a surface type and a volume type. The surface coil has an advantage to increase local resolution, where the volume coil has an advantage to get the uniform signal field. The volume coil has a cylindrical shape to generate a uniform magnetic field and is called birdcage coil. The uniformity is disturbed, however, when an asymmetrical subject like a knee is inserted. The inductive coupling in radio frequency probe is one of the factors to improve the image [6-10].

In the present study, a wireless coil is inserted in the birdcage coil to improve the SNR in MRI. An inductively coupled wireless RF coil with the birdcage coil has been developed in whole-body magnetic resonance (MR) scanners in the present study.

2. METHODS

Inductive Coupling Dual Coils System

An inductive coupling dual coils system was designed (Figs. 1 & 2) [11]. The system includes two coils: a birdcage coil and a wireless coil of a cylindrical type or of a Helmholtz type.

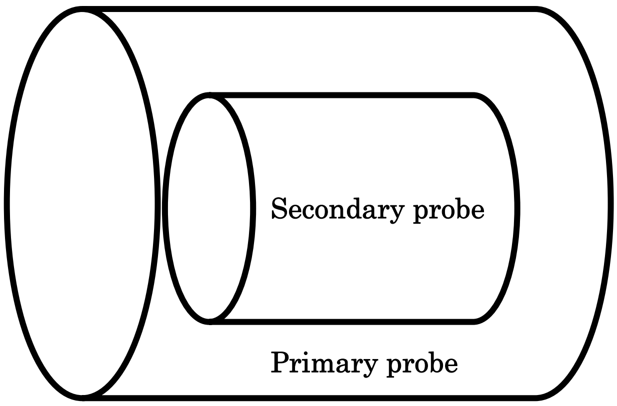

Fig. 1: Inductively coupling RF probe

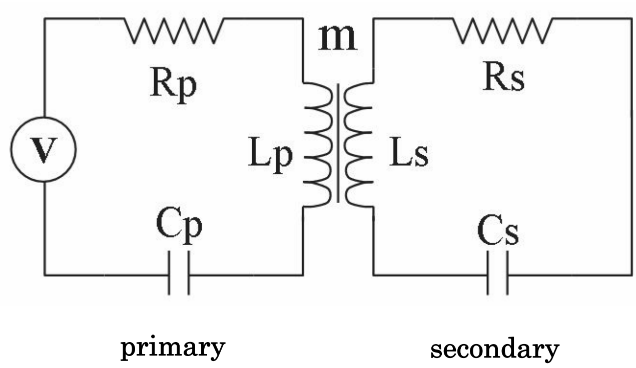

Fig. 2: Equivalent circuit of dual coils.

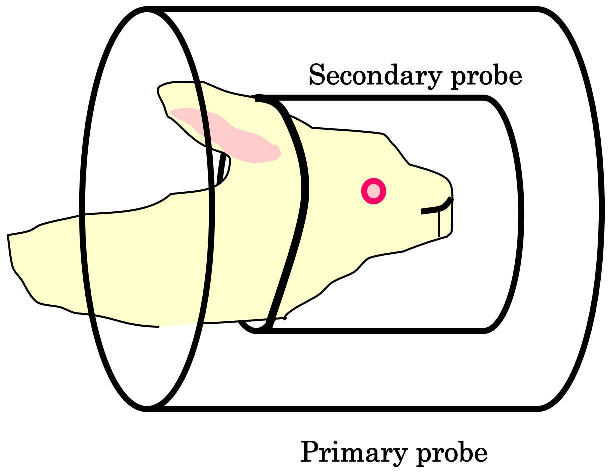

Fig. 3: Animal test.

Animal Test

The RF probe of the cylinder with 280mm diameter and with 280 mm height was applied for the primary coil, which is conventionally used for human head. To generate a uniform magnetic field at resonance, a wireless probe of the secondary coil was manufactured in a cylindrical type, which is the same kind of shape as the primary coil. The coil consists of eight elements along the lateral surface of the plastic cylinder. The secondary coil has dimensions of 120 mm diameter and 100 mm height to fit rabbit's head (Figs. 3 & 4). The secondary coil was located at the centre of the primary coil.

Magnetic resonance images were taken on a rabbit's head under anesthesia in RF probe with and without the wireless secondary probe, respectively. T1-weighted and T2-weighted images at spin-echo sequence (TR/TE=4000 ms/96 ms) were compared between two types of RF coil arrangements. Resolution of the image was 0.39 mm × 0.39 mm × 3.0 mm voxel.

Phantom Study

The frequency of resonance was adjusted to 64 MHz, which corresponds to 1.5 teslas of a MR system (Siemens Magnetom Vision) (Fig. 6). Fig. 6 shows MR system with the volume coil, which was applied to the phantom. To minimize the shift of resonance frequency with the inserted wireless coil, the reactance component is neutralized with capacitance of high voltage proof.

Several magnetic resonance images were taken on a cylindrical phantom of copper sulfate of 50 mm diameter and 150mm height (Fig. 7).

The signal to noise ratio (SNR) of the image was compared about the position of the coils: a birdcage alone, longitudinal and vertical. Fig. 8 shows two positions in the phantom study: longitudinal and vertical.

Human Knee

Another coil of a Helmholtz type (Fig. 5) was manufactured in the dimension of 120 mm diameter to be applied to the human knee, where the cylindrical type is hard to fit. Magnetic resonance images were taken on a human knee of a volunteer.

Signal to Noise Ratio

The methodology to calculate SNR (R) from I (the mean intensity of the signal in the region of interest) and B (the standard deviation of the mean intensity in the background) in equation (1) is based on the National Electric Manufactures Association (NEMA) standards.

Fig. 4: Secondary probe in animal test.

Fig. 6: Magnetic resonance scanner.

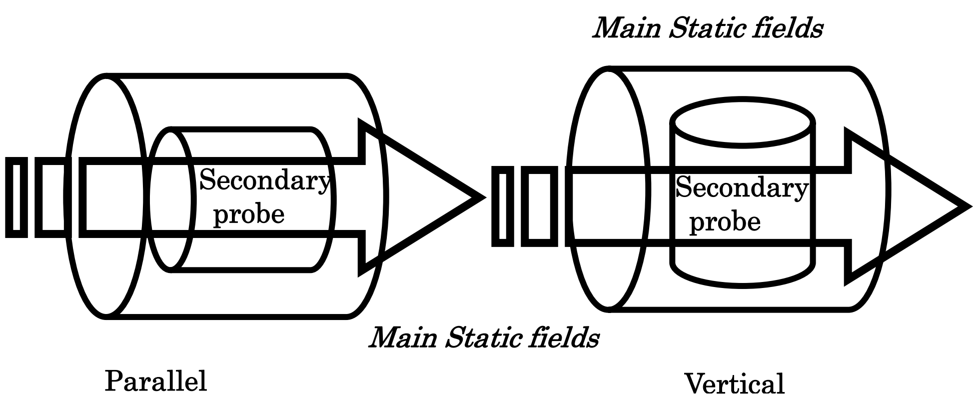

Fig. 5: Two types of position between primary and secondary probes: parallel and vertical.

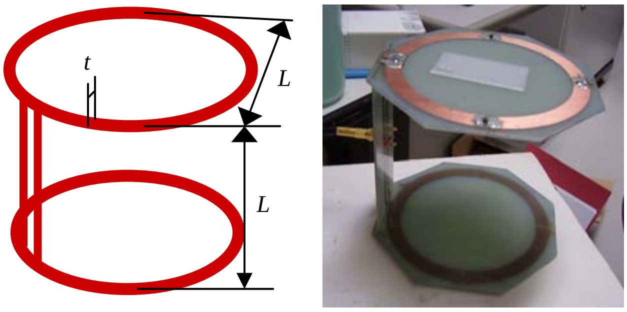

Fig. 7: Helmholtz coil (wireless coil)
L=120 mm, *t*=10 mm.

$$R = I / B \quad (1)$$

The standard deviation in the background is calculated on the image composed from subtraction signal of two images with the same parameter.

3. RESULTS

Fig. 8 shows the image of the sagittal section of rabbit. The experimental results on rabbit's head show that SNR with the secondary wireless coil is higher than that without the wireless coil (Table 1).

Fig. 9 shows the proton density image of the longitudinal section of the phantom column at each position of coils in the phantom experiment. Table 2 shows SNR calculated from each image of phantom. The experimental results with the phantom show that SNR with the additional wireless coil winded around the phantom is two times higher than that without the wireless coil (one coil).

Fig. 10 shows the proton density image of the human knee in each position of coils. Fig. 11 shows five regions to measure SNR in the image around the articular cartilage of the knee. Fig. 12 shows SNR calculated from the image at each region in three positions of coils. The

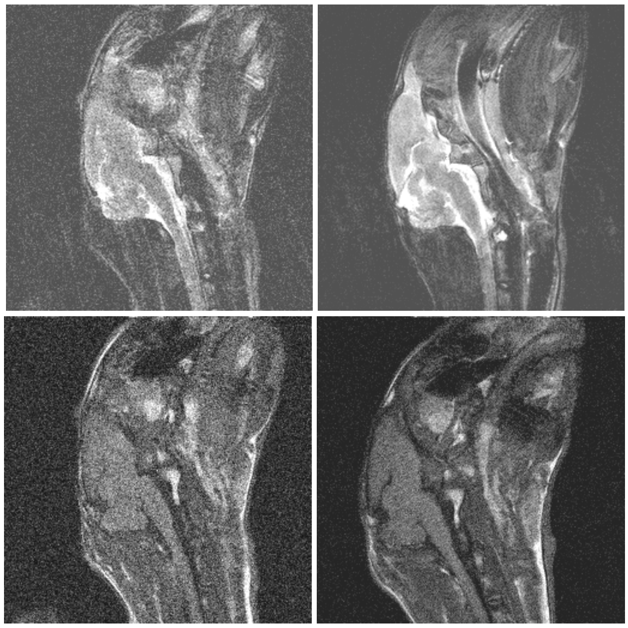

Fig. 8: Rabbit's head; T2-weighted image, top; T1-weighted image, bottom; without wireless coil, left; with wireless coil, right

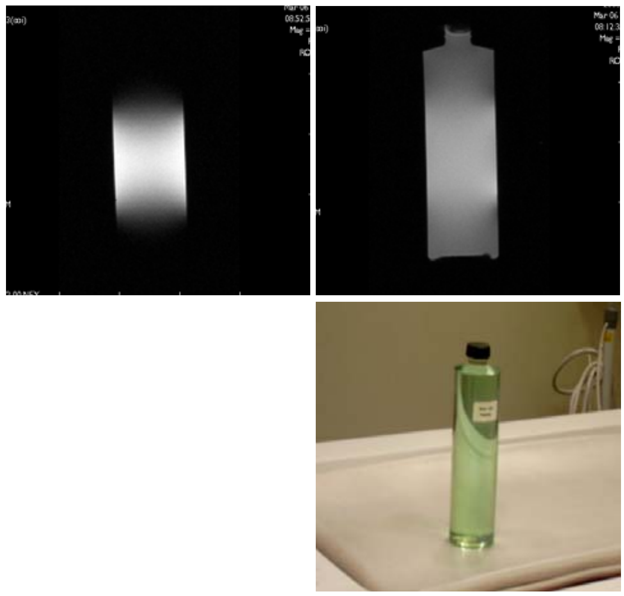

Fig. 9: Phantom study: parallel, left; vertical, right: phantom, bottom right.

Table 1: Signal to noise ratio in animal test

SNR	Head with wireless	Head alone	Improvement
T1weighted image	13.3	9.1	1.5
T2weighted image	23.8	11.2	2.1

Table 2: Signal to noise ratio in phantom test.

Phantom	Head alone	Pallarel	Vertical
SNR	11.3	28.2	25.1

results in proton images of human knee show that SNR in the vertical position is almost double that with the birdcage alone in most of regions.

The results show that the developed inductively coupled coil improves the signal to noise ratio.

4. DISCUSSION

The articular cartilage of the knee joint is easy to be degenerated with aging. Taking the magnetic resonance image of the articular

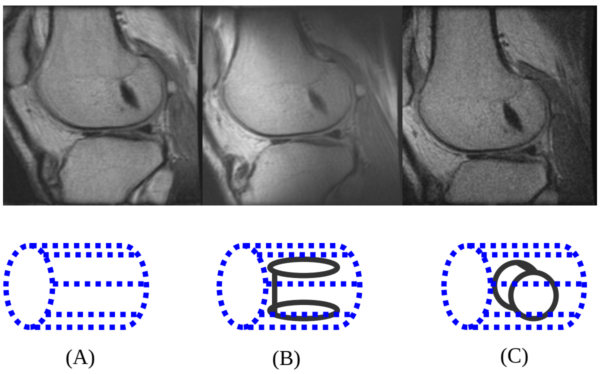

Fig. 10: Proton density images of knee. (A) birdcage alone, (B) wireless vertical, (C) wireless horizontal.

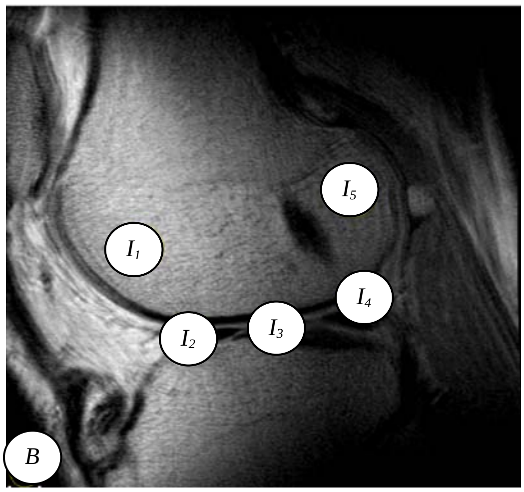

Fig. 11: Regions to measure SNR in proton density image of knee

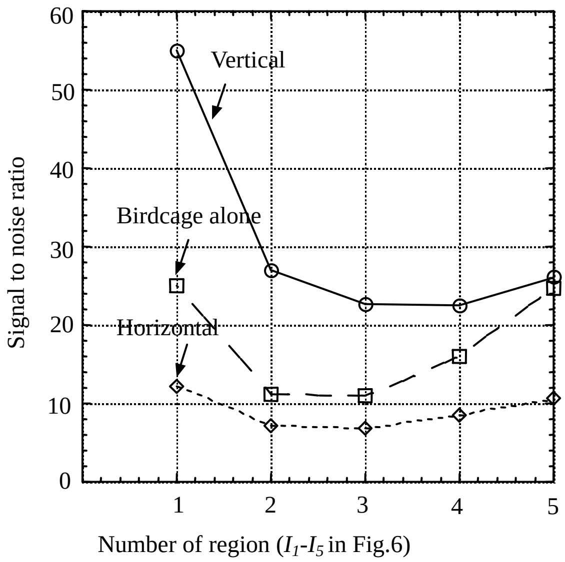

Fig. 12: Signal to noise ratio in each region (I_1-I_5 in Fig. 11)

cartilage, however, is not easy, because the area includes only small amount of proton. Maximizing the signal to noise ratio of the radio frequency probe is effective to improve the quality of the image.

Helmholtz coil is selected for the wireless coil to get uniform magnetic field among the space between two circles of the coil. The electric current in the birdcage coil increases by inductive coupling with the wireless coil, which improves signal detection. The variation of resonance frequency with inductive coupling between coils should be considered, because it affects SNR. The additional inductively coupled wireless radio frequency coil can be simply applied to conventional radio frequency coils to improve the quality of magnetic resonance images.

The volume ratio of the subject to the inner space surrounded by the coil is called filling factor. Maximized filling factor increases signal to noise ratio in magnetic resonance image with the volume type of the radio frequency coil. Experimental results on rabbit's head show that a small cylindrical secondary coil is effective to increase the filling factor. A wireless coil of flexible material should be easy to adjust the subject and improve the filling factor.

Moderate inductive coupling between primary and secondary coils generates resonance, and increase electric current in the primary coil, which might improve detection efficiency.

5. CONCLUSION

The experimental results show that the developed inductively coupled Wireless Radio Frequency coils are effective to improve the signal to noise ratio on magnetic resonance images and to be applied to the human knee joint.

6. ACKNOWLEDGMENT

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