A Novel Flexible Flex Cable Antenna (FFCA) for Foot MR Imaging

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Introduction:

Conventionally, eight channels phase array head coil or birdcage coil [1] is used to acquire foot MR signal. However, it has a low fill factor. Flexible coils [2] and antennae can overcome this limitation. In recent years, flexible coils have been proposed for privileged sites of human body, such as shoulder, but not for figure and foot. In this study, we design, build and test a novel flexible flex cable antenna (FFCA) for higher SNR (signal-to-noise ratio) MR imaging for foot. To verify the feasibility of this design, this work included foot phantom tests and human foot tests.

Materials and Methods:

Based on the monopole antenna theory [3], the design of FFCA was consist of a usual flex cable (60 cm in length), a tuning/matching circuit and a signal transmission line (Figure 1), FFCA was only used to receive signal, the body coil was used to excite. The flex cable has 60 elements, the diameter of each element is 1.0 mm, and the interval between two elements is 0.3 mm. The tuning and matching circuit was composed of 3 tunable capacitors (C_1, C_2, and C_3) and a fixed capacitor (C_4). C_1 was used to fine-tune the frequency to Larmor frequency, C_2 serveed for the reflection coefficient (S_{11}) adjustment, C_3 was used to tune the resonant frequency roughly, and C_4 was designed for matching the circuit to 50 Ohms. The antenna connected with a 3T whole-body MRI system (Signal™; GE Medical Systems) via a signal transmission line (1 m in length). To evaluate the feasibility of the proposed FFCA, in vitro and in vivo experiments were carried out on a 3T MR system. At the same time, we have compared the SNR of FFCA and eight channels phase array head coil (Signal™; GE Medical Systems). A foot phantom (plastic) was used to test the homogeneity and SNR of FFCA. The phantom was full of tap water. Scanning parameters for the sagittal images were: sequence: FSE T_1, repetition time (TR) = 500.0 ms, echo-time (TE) = 12.6 ms, slice thickness = 3.0 mm, FOV= 26×26 cm, Matrix = 256×256, and NEX = 4.0; Scanning parameters for the axial images were: sequence: FSE T_1, repetition time (TR) = 500.0 ms, echo-time (TE) = 12.6 ms, slice thickness = 3.0 mm, FOV = 26×26 cm, Matrix = 256×256, and NEX = 4.0; FSE T_2, repetition time (TR) = 3000.0 ms, echo-time (TE) = 122.0 ms, slice thickness = 3.0 mm, FOV= 26×26 cm, Matrix = 256×256, and NEX = 4.0. After in vitro tests, we tested the antenna using healthy human foot. The scanning parameters were: sequence: FSE T_1, repetition time (TR) = 500.0 ms, echo-time (TE) = 14 ms, slice thickness =2.0 mm, FOV = 40×40 cm, Matrix = 256×256, and NEX = 4.0. All experiments parameters of FFCA and eight channels phase array head coil were the same.

The SNR was calculated as: $SNR = S/SD$. Where S was signal amplitude of the region of interest (ROI), SD was the standard deviation of noise in the ROI.

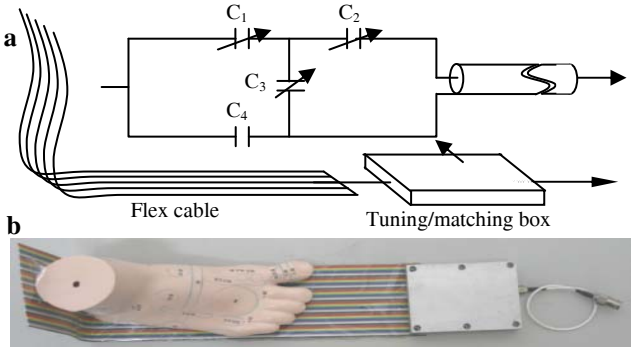

Fig.1 Schematic representation of the proposed FFCA (a) and the photo of FFCA with foot phantom.

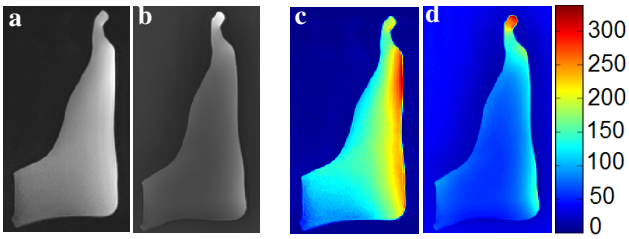

Fig 2. Sagittal image (FSE T_1) of foot phantom using FFCA (a) and eight channels phase array head coil (b). The SNR maps of FFCA and eight channels phase array head coil are shown in (c) and (d).

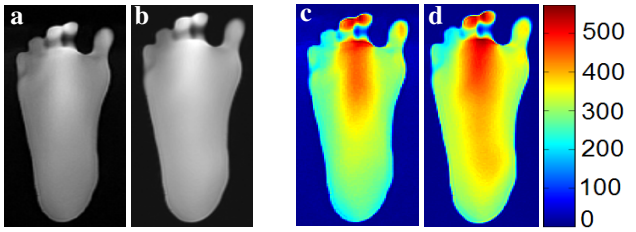

Fig 3. Axial images of foot phantom using FFCA are shown in (a) and (b) (FSE T_1 and T_2). The corresponding SNR maps of FFCA are shown in (c) and (d).

Results:

From the foot phantom sagittal MR images (Fig 2), the homogeneity of the image using FFCA is linear in the center of phantom (Fig 2 a). The homogeneity of the image using eight channels phase array head coil is nonlinear in the center of phantom (Fig 2 b). The homogeneity of FFCA is better then eight channels phase array head coil (Fig 2 a and b). The SNR of FFCA is higher then eight channels phase array head coil (Fig 2 c and d). Fig 3 shows FSE T_1 and T_2 images of foot phantom using FFCA and the corresponding SNR maps. The results indicate that the SNR of images using FFCA approximate to 350. From the axial MR images of human foot (Fig 4), the images of FFCA show the tissue and joints clearly, and the SNR is higher then eight channels phase array head coil.

Discussion:

The FFCA using flex cable was flexible and suitable for foot MR imaging. Because the flex cable was near the foot, the fill factor is higher than traditional birdcage coil and eight channels phase array head coil. Higher fill factor could bring higher SNR. To validate its feasibility and effectiveness, phantom and in vivo experiments was carried out. The images of human foot were acquired by FFCA (Fig 4 a) and eight channels phase array head coil (Fig 4 b). The SNR of foot images using FFCA is higher then eight channels phase array head coil. In our further work, we will build up a shoe-like FFCA to implement inexpensive foot imaging with high SNR.

Conclusion:

In this study, we developed a novel flexible antenna for human foot MR imaging which is consisted of a flex cable and tuning/matching box. Compared to phase array coils, experimental results show that the FFCA have a higher SNR and better magnetic field homogeneity, and it can be easily designed for individual foot shape with higher fill factor. Meanwhile, the feasibility of FFCA has been validated by phantom and healthy human foot experiments. In the near future, it is believed that as a flexible antenna, the FFCA can be applied for hand or other unusual shape of human body.

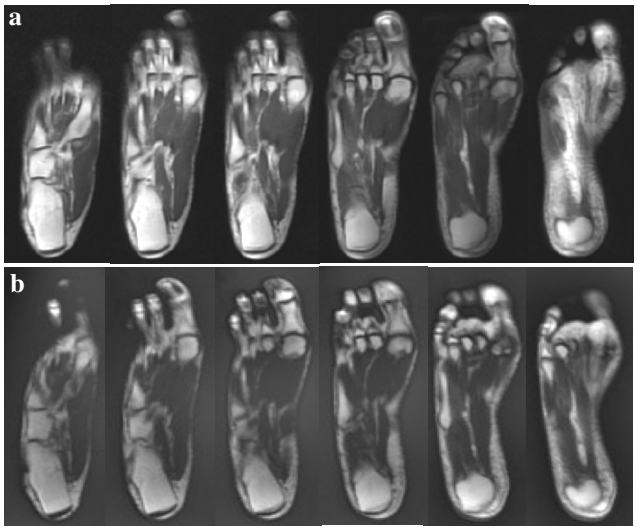

Fig 4. Axial images (FSE T_1) of human foot using FFCA (a) and eight channels phase array head coil (b).

References:

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