A target-field design of open multi-purpose coil for musculoskeletal MR imaging at 3T

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Target audience: MR physicists and technologists, musculoskeletal radiologists.

Purpose:

MRI plays an important role in diagnosing the diseases of musculoskeletal tissues at different body parts, such as ankle, knee, elbow, hand and wrist. Besides, the evaluation of joint movement under dynamic conditions can provide important information for detailed assessment of joint abnormalities, which demands that the RF coil has a large joint movement region[1, 2]. It's highly anticipated to develop a new RF coil to examine the musculoskeletal tissues with satisfied transverse magnetic (B_1) field homogeneity, high SNR and large joint movement region. In this study, based on the time-harmonic target-field method[3], we proposed a kind of open multi-purpose coil (OMC) for MR imaging of musculoskeletal tissues at different body parts with homogeneous B_1 field and high SNR.

Materials and Methods:

The OMC has a three-plane structure. We designed and built two OMCs (OMC1: 10cm×10cm×10cm (for ankle, elbow, hand and wrist); OMC2: 15cm×15cm×15cm (for knee)) for achieving a high filling factor. The design and fabrication process of each OMC is as follows. According to the time-harmonic target-field method, firstly, the current densities on the surface of the three planes were expressed in terms of trigonometric basis functions with unknown coefficients. Then the expressions were applied to obtain the B_1 field at each space field point in the region of interest (ROI, a sphere located at the center of the coil with a diameter half of the side length of the plane) and dissipated power of the coil. For solving the unknown coefficients of the current density, an object function was constructed with respect to the total least square errors of the B_1 field at all the target-field points in the ROI with the penalty function expressed in terms of the dissipated power. By minimizing the object function with respect to the unknown coefficients, the current density can be obtained. Finally, we employed the stream function method to establish the concrete winding pattern on the three planes of the coil. After obtaining the winding pattern, the coil was built with the copper strip (width: 2 mm (OMC1), 3 mm (OMC2); thickness: 40 um) bending along the winding lines. The coil was matched to 50 Ohms at 127.72 MHz through a tuning/matching circuit and a signal transmission line (Fig 1). In this study, the coil is only used to receive signal while the body coil is used to excite. The coil was connected with a 3T whole-body MRI system (Signal™; GE Medical Systems) via a signal transmission line (length: 0.5 m).

To evaluate the feasibility of the proposed coils, in vitro and in vivo experiments were carried out. A phantom with tap water (15.3cm×7.3cm×13.6cm) was used to test the B_1 field homogeneity and SNR of the OMC1. For imaging of elbow, ankle, hand and wrist, the OMC1 was placed under the joint tissues while the OMC2 was put on the top of the joint for imaging of knee. The scanning parameters were: sequence: FSE (T1WI: repetition time (TR)=600.0 ms, echo time (TE)=12.4 ms; T2WI: TR=3000.0 ms, TE=120.0 ms; PDWI: TR=3000.0 ms, TE=12.4 ms), slice thickness=6.0 mm, slice spacing=0mm, Matrix=256×256, and NEX=4.0 (hand and wrist, ankle and knee under normality) or 2.0 (elbow under normality and flexion, ankle and knee under flexion). To evaluate the safety of the OMC1 and OMC2, we utilized the optical fiber thermometer to measure the temperatures of the surface of each coil under three different positions during the scan of two continuous sequences (3min48second) and the probes were placed between the tissues and the coil.

Results:

As shown in the axial and coronal phantom images of different slices (Fig 2), the B_1 field homogeneity of the proposed OMC with three-plane structure is satisfied and the SNR is high. The images of musculoskeletal tissues at different body parts (Fig 3) render fine anatomic details and demonstrate clear contrast between different joints and tissues. Besides, the images of elbow, knee and ankle under flexion also show clear contrast between different joints and tissues, high SNR and good homogeneity. The largest temperature increments of the three positions during the scan are 1.8℃ (OMC1) and 2.1℃ (OMC2) respectively, which proves the safety of the coils.

Discussion & Conclusion:

The B_1 field distribution is homogeneous and the SNR is high because of the target-field design and the three-plane structure of the OMC. The in vitro and in vivo experimental results indicate that the proposed OMC is feasible for MR imaging of musculoskeletal tissues at different body parts. Besides, the open structure of the OMC can provide a large joint movement region and is more suitable for real-time evaluation of musculoskeletal tissues under dynamic conditions, which will be studied in the future using the proposed OMC.

In conclusion, we developed a kind of target-field method based, open multi-purpose RF coil with a satisfied B_1 field homogeneity, high SNR and large joint movement region, which can be applied in the musculoskeletal MR imaging, especially under dynamic conditions.

References:

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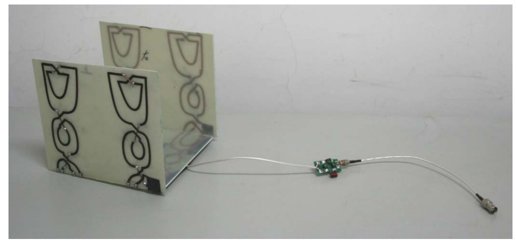

Fig 1. The photo of OMC2 (OMC1 has the similar structure.).

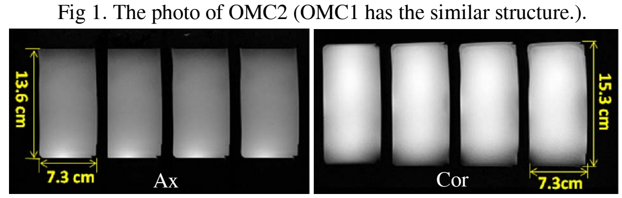

Fig 2. The axial and coronal images (T2WI, FOV: 24×24cm) of the phantom by using the designed OMC1 (10cm×10cm×10cm).

Fig 3. The MR images of musculoskeletal tissues at different body parts by use of OMC1 or OMC2 (A. hand and wrist (T1WI, FOV: 24×24cm), B. ankle (T2WI, FOV: 30×30cm), C. elbow (PDWI, FOV: 28×28cm), D. knee (PDWI, FOV: 24×24cm), E. elbow (PDWI-Sag), knee (PDWI-Sag) and ankle (T2WI-Sag) under flexion).