Constellation Coil for Multi-nuclear Imaging

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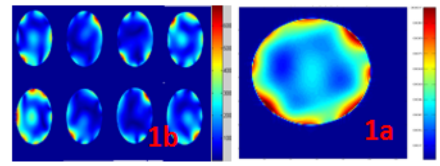
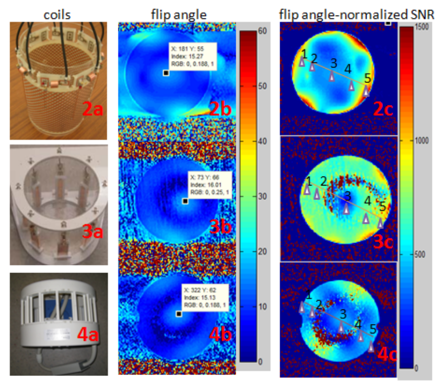
INTRODUCTION: MR imaging of nuclei other than proton has been used to investigate metabolism in humans and animals. Additional imaging modalities such as sodium (23Na) MR have the potential to increase the sensitivity and specificity of cancer detection[1]. Currently, most transmit or receive RF coils are resonant structures, such as birdcage and loop coils, which are tuned to be resonant at the Larmor frequency of the nuclei of interest. Dual-tuned coils are desired for enhanced multi-nuclear imaging. They are difficult to build however: 1) MRI observable nuclei other than hydrogen are not as abundant. As a result image SNR is very low and use of phased array to maximize receive sensivity is often necessary. 2) To obtain a homogeneous B1+ excitation field, use of birdcage coil for RF transmission is the standard arrangement. Existing multi-nuclear coils therefore tend to be very complicated -- many de-tuning and de-coupling circuits are needed for a multi-nuclear coil to accommodate multiple coil structures one for each of frequencies and Tx/Rx functions. Such a complex arrangement may lead to compromises in performance. The present study investigated the feasibility of using a single coil structure for both transmit and receive, and for both 1H and 23Na imaging on 7T, without any de-tuning or de-coupling circuits.

METHODS AND RESULTS: "Constellation coil" was introduced recently, which prioritizes field optimization-based Tx/Rx improvement with a RF continuum structure, and accommodates highly parallel Tx/Rx through distributed multiple ports[2,3]. The continuum structure is broadband, which can support broadband RF current patterns by driving/receiving with distributed multiple ports, possibly without concerns over decoupling or mode structure. It therefore is a possible candidate as a simple coil structure for multi-nuclear imaging.



In this feasibility study a helix constellation coil structure[2] was further built upon to support dual-frequency transmit and receive functions. The structure has two layers of helix conductor strips sandwiching a 0.79mm-thick FR4 board, which are 4.5mm by 282mm traces with 4.5mm gap, and rotated 45° with respect to the main cylinder axis giving 200mm z-length around a cylindrical former (Fig.2a). Two constellation coils of this same structural design but of slightly different diameters were involved in the study: Coil A, shown in Fig.2a, has a diameter of 20cm, and Coil B has a diameter of 23.5cm. Coil A, with 8 channel parallel Tx-Rx support for 7T proton imaging previously established, was used as a baseline. Coil B, also with the same proton imaging capability previously established, had a separate set of 8 sodium ports added to its structure, with four of them for Tx and Rx and the other four for Rx only in imaging tests performed in this study. These additional ports were matched to 50ohm at sodium Larmor frequency using LC circuits. The original 8 proton ports were untouched and kept functioning. Because the same helix structure was used for both transmit and receive, and for both frequencies, no de-tuning or decoupling circuits were necessary.

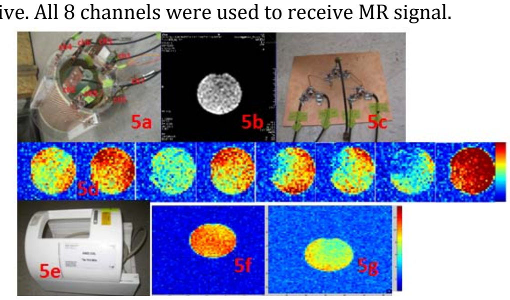


Coils A and B were evaluated in terms of their functionality and performance for transmit and receive for, respectively, 7T proton (297.2MHz) and sodium (78.6MHz) on a Siemens 7T scanner (8 channel parallel transmit–capable at proton frequency). Previous phantom and volunteer tests of Coil A focused on transmit and in vivo imaging evaluations. Compared with a conventional 8-element stripline coil, phantom results indicated that Coil A could produce larger average |B1+| at tested transaxial slice locations given same total output power from the eight RF power amplifiers. The current study further evaluated the SNR performance of Coil A. In one imagine test, RF excitation targeted 60 degree flip angle at the center of a transaxial slice. Imaging parameters include: TR=3000ms, TE=4.7ms, #signal averages=1, 128x128 matrix, FOV=210 x210mm², and slice thickness=2mm. The optimum combined SNR map (Fig.1a) was calculated using Sloader, a Siemens SNR quantification tool. And the SNR maps corresponding to individual channels were shown in Fig.1b. Imaging experiments were further conducted to compare Coil A (Fig.2a) with the conventional 8-element stripline coil (Fig.3a) and a commercial 7T birdcage knee coil from InVivo (Fig.4a). These imaging experiments all used the same phantom and with excitation pulse scaled to target 15° flip angle at the center of the same transaxial slice location. When each of the three coils was used for transmit and receive, an excitation flip angle map was additionally acquired. The acquired flip angle maps are shown in Fig.2b, Fig.3b and Fig.4b – these flip angle maps were used to remove flip angle induced bias in SNR comparison through normalization. The flip angle-normalized SNR are showed in Fig.2c, Fig.3c and Fig.4c respectively. Flip angle-normalized SNR values at five points located on the line marked in Fig.2-4 are additionally listed in Table 1.

Table.1: flip angle-normalized SNR comparison

Points	spiral constellation	stripline coil	birdcage coil
1	909	668	509
2	550	635	451
3	427	188	444
4	508	709	398
5	933	780	443

For Coil B, the 8 additional sodium ports are located at the center section of the coil structure, and are separated azimuthally by 45°. All ports have transmit and receive capability, with T/R switches and pre-amps on coil (Fig.5a). A 1-to-4 splitter (Fig.5c) was used to split the input power and drive the constellation coil from 4 ports with equal amplitudes and 90° phase increments to emulate CP mode drive. All 8 channels were used to receive MR signal. Phantom image results were obtained with a GRE sequence (Fig.5b). Additional parameters include: TR=200ms, TE=3.5ms, # signal averages=1, 64x64 matrix, FOV=216x300mm², slice thickness=25mm. Further, Sloader was used to quantify the optimum combined SNR (Fig.5g). And the SNR maps corresponding to individual channels were showed in Fig.5d. For comparison, a 7T birdcage sodium knee coil from Rapid (Fig.5e) was used to transmit and receive with the same phantom and sequence parameters. SNR map is shown in Fig.5f, which has SNR around 9~12 across a center transaxial slice, while Coil B obtained 7~11 SNR at the same location (Fig.5g). In both imaging acquisitions a 90° flip angle was maintained at the center of slice.



DISCUSSIONS: The feasibility of using a same constellation coil structure for transmit and receive for multi-nuclear imaging was demonstrated. One single coil structure could be used as transmit and receive coil for two distinct frequencies without any de-tuning or de-coupling circuits. This is an advantage over conventional dual-frequency coils that require sophisticated design, construction and tuning. A constellation coil in comparison only needs to add ports and match the ports to 50ohm at respective Larmor frequencies through LC circuits. No explicit guidance was available in coming up with the helix structure or the port locations. Yet the present study showed that the helix constellation coils offered good SNR performance when compared to the 8-element stripline coil and a commercial 7T proton birdcage knee coil, especially near the surface / at the center of the phantom. There are immediate issues to be further investigated. In this largely symmetric configuration individual port SNR maps indicate that some ports, e.g., ch5 (Fig.1b) and ch8 (Fig.5d), were much more sensitive than other ports, e.g., ch3 (Fig.1b) and ch7 (Fig.5d). For sodium imaging, a B1+ excitation field profile similar to that of a birdcage coil was obtained with 4-port drive. The SNR in center transaxial slice appeared to be lower however than that of a commercial 7T sodium birdcage knee coil.

REFERENCES: [1] Seunghoon Ha *et al* 2010 *Phys. Med. Biol.* 55 2589. [2] Y. Zhu, *18th ISMRM*, p 46, 2010. [3] Y. Zhu, *18th ISMRM*, p 1518, 2010.