Role of Birdcage Volume Resonators for High-Resolution Wrist Imaging at High and Ultra-High Fields

Yusuf A Bhagat[1], Po-Hsiang Lai[1], Xu Zhu[1], Insoo Kim[1], and Zhouyue Pi[1]
[1]*Emerging Technology Lab, Samsung R&D Institute America, Richardson, Texas, United States*

Purpose

This educational review draws attention to the role of birdcage volume resonators for a simple solution for high-resolution microstructural imaging of the human wrist at high (3T) and ultra-high (UHF, ≥7T) fields. Birdcage coils provide exceptional field uniformity, sensitivity and ability to operate in quadrature.

Outline of Content

The human wrist or distal radius bears strong clinical significance owing to its susceptibility to fragility fractures [1], a consequence of poor bone quality. Parameters reflecting bone quality serve as markers for changes in cancellous or trabecular bone (TB) microarchitecture [2]. Such changes are strong indicators of bone resorption in disease (e.g. osteoporosis) or bone formation in response to treatment. Peripheral skeletal sites such as the wrist are amenable to high-resolution micro-MR imaging (µMRI) permitting quantification of TB microarchitectural changes. Currently, such wrist images are acquired using phased-array Rx coils [3-4]. Although the use of phased-arrays facilitates parallel imaging, it also necessitates body or local volume coils for Tx, which can exceed the specific absorption rate (SAR) constraints depending on the sequence used. Also, when migrating to UHF to capitalize on the increased SNR relative to 3T [5], a technical deterrent is the lack of commercially available 7T-dedicated wrist coils. We will explore various features that provide insight into the utility of wrist birdcage volume resonators for high-resolution TB µMRI at 3T and 7T.

Coil Design and Construction: Steps detailing Tx-Rx quadrature coil design and construction will be reviewed. The BirdcageBuilder software [6] can be used to determine the necessary capacitances using coil geometry, dimensions, desired current pattern, calculated inductance and pre-assigned resonance frequency (123.26 MHz and 297.22 MHz) for low-pass (LP) or high-pass (HP) (**Fig. 1**) configurations. Copper tape and circuit components are mounted on polyethylene formers preventing contact with any tissue. Elliptic cylindrical formers allow for tighter coupling of the coil to the anatomy relative to circular formers. Variable capacitors can be added to achieve ideal tuning and matching to ~50Ω for both input channels (0° and 90°) when loaded with a human wrist. RF traps can help avoid unwanted currents on the cable shields. Coil performance can be estimated by measuring SNR in tissue-equivalent phantoms or ideally, in vivo, and by estimating the S-parameters and the quality ratio (Q, $Q_{unloaded}/Q_{loaded}$) on a network analyzer. Our results yielded Q ratios of 1.6 and 4.4 for 8-strut LP and 12-strut HP coils at 3T and 7T [7], respectively, for Siemens scanners.

SAR Estimation: Methods to determine peak SAR value averaged over 10g of local tissue for these coils will be reviewed. In our work, we have relied on a temperature mapping approach using a polyacrylic acid gel according to NEMA specifications [8]. A 2D GRE sequence (TR/TE=90/3.6 ms, Matrix=128x128, Concats=2, NEX=1, Measurements=100, SRFExcit 1H=100.0V) was performed at 95% SAR for ~40 minutes where the temperature measurements (using a fiber optic probe) yielded the heating rate of the coil and allowed determination of the de facto hot spot in the gel phantom. The temperature drop in the same location was then measured over a similar interval to estimate the cooling phase. The peak SAR values for the birdcage coils here were 2.55 W/Kg and 6.63 W/Kg at 3T and 7T [7], respectively, which were well below the IEC-based SAR limits (local SAR of 20 W/Kg) for extremities.

Patient Setup: Previously, wrist images have been acquired with subjects in the head-first prone (superman) position with the arm stretched overhead and inserted in the coil [3-4]. This setup can increase patient discomfort due to arm/shoulder strains and result in motion-degraded images. In our studies, we have performed wrist imaging in the feet-first supine position, with the wrist placed in the RF coil and the arm positioned adjacent to the hip (**Fig. 2**). The entire imaging protocol including setup time was ~20 min and resulted in high patient compliance. Despite the off-center nature of the acquisitions, gradient non-linearity was a non-issue.

Image Acquisition and Quality: Most high-resolution imaging of the wrist at 3T and 7T utilizes 3D GRE techniques with the in-plane resolution and slice thickness ranging from 169-270 µm and 300-500 µm, respectively [3-4]. Limitations of GRE techniques are low SNR and their increased sensitivity to off-resonance effects arising from susceptibility differences at the bone and bone marrow interface. The 3D Fast Large Angle Spin Echo (FLASE) technique provides a robust alternative for high-resolution TB µMRI. Previous 3D FLASE MR wrist imaging studies at 1.5T have reported scan times of 10.5-12.5 min for a voxel size of 137x137x410 μm^3 (TR/TE=80/11 ms, α=140°, FOV=70x51x13 mm^3, Matrix=512x372x32) [9]. We will discuss optimizations to the FLASE pulse sequence that have allowed a 30% reduction in scan time (7min 41sec) with minimal penalties for SNR and image quality as determined by Bloch simulations, and in phantom and wrist scans (Fig. 3).

Reproducibility: The reproducibility of image quality (SNR) and quantitative TB microstructural parameters of scale (bone volume fraction (BVF)), topology (plate-like to rod-like character of TB) and biomechanics (stiffness) as derived from virtual bone biopsy processing [9] can further attest to the performance of the coils. We observed coefficients of variation of 1.1-5.8% in these parameters using the same 3D FLASE sequence at 3T and 7T [7].

Summary

This educational e-poster highlights the value of birdcage volume resonators for rapid (<8 min) 3D high-resolution spin-echo imaging of the wrist at 3T and 7T. Further we aim to show that custom-built Tx-Rx quadrature birdcage resonators yield high SNR at minimal SAR and permit comfortable feet-first supine subject positioning. The merits of Tx-Rx birdcage coils are better realized at UHF due to the frequent absence of a dedicated body Tx coil.

References: [1] Harvey. Nat Rev Rheumatol 6:99 2010. [2] Griffith. Ann NY Acad Sci 1192:45 2010. [3] Krug. Radiol Clin N Am 48:601 2010. [4] Friedrich. Semin Muscul Radiol 16:88 2012. [5] Bhagat. JMRI 33:372 2011. [6] Chin. Concepts MR Engineering 15:156 2002. [7] Bhagat. Proc Ortho Res Soc. 1502 2013. [8] NEMA Standards MS 10-2006. [9] Lam. Bone 49:895 2011.

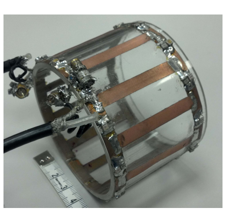

Fig. 1 : 12-strut high-pass 7T birdcage coil for high-resolution wrist imaging.

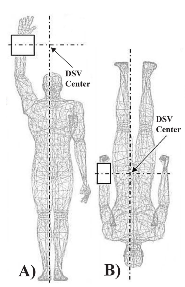

Fig. 2 : A) Prone overhead and B) supine feet first positions for wrist imaging. Further away from the DSV center leads to scans in less homogeneous gradient fields.

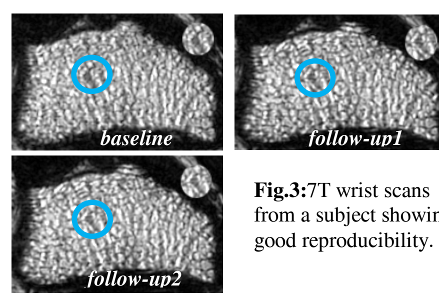

Fig.3:7T wrist scans from a subject showing good reproducibility.