

## High resolution radial 3D ultra-short echo time imaging in vivo

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**Target Audience** – Researchers interested in 3D radial high resolution sequences, UTE imaging and 3D image reconstruction

**Purpose** – Ultra short echo time (UTE) imaging is a promising MR method, which allows imaging of materials and tissues with very short  $T_2$  relaxation times. Implementations using slice selective 2D radial acquisitions [1] have been applied to image cortical bone [2] or the meniscus [3]. A different approach to UTE imaging is using radial center-out 3D acquisitions (“spiky ball”). Spiky ball acquisitions employ very short, hard RF pulses and, unlike the slice selective 2D acquisition, there is no need to repeat the excitation with reversed slice gradients [1]. Besides obtaining isotropic 3D data the spiky ball acquisition scheme is robust against fold-over artifacts because readout oversampling can be employed in all directions. Another advantage is the extreme oversampling of the k-space center, making radial 3D acquisition very immune against motion and potentially provides improved SNR. This work explores the general feasibility of high resolution spiky ball UTE acquisitions *in vivo* using a head scan as an example.

**Methods** – A 3D radial center-out sequence was implemented on a 3T clinical scanner (Magnetom TIM Trio, Siemens Healthcare, Erlangen, Germany). The sequence uses hard RF pulses with 20 $\mu$ s duration and flip angle of 10°. To minimize echo time the ADC is switched on immediately after the RF pulse with the radial readout gradient following 60 $\mu$ s later. This delay between switching on the ADC and ramping up the readout gradient was implemented to avoid digital filtering artifacts for the first ADC points (dead-time of the ADC). The radial readouts use an oversampling factor of 3 (dwell time 1.9  $\mu$ s) and are acquired center-out and center-in, providing two echoes (TE1/TE2/TR=60  $\mu$ s / 2.3 ms / 4.3 ms), followed by spoiler gradients. Every 27 spokes (116 ms) a fat saturation pulse was applied to achieve partial fat saturation. Due to the readout oversampling in all directions the FOV was reduced to (160 mm)<sup>3</sup>. With an acquisition matrix of 300 x 300 x 300 the resulting effective voxel size was (0.53 mm)<sup>3</sup>. A total number of 181,154 spokes were acquired with total scan duration of 14 min. The sequence includes an additional template scan for gradient delay estimation, which is acquired prior to the UTE data acquisition. Gradient delays were compensated during image reconstruction which was performed with a recently published state-of-the-art gridding algorithm using a time efficient iterative sampling density correction [4]. To reduce memory demand on the reconstruction system a grid scaling factor of x1.6 was applied, resulting in an output matrix of 480 and FoV of 256 mm. Even with the x1.6 grid scaling factor the reconstruction process required peak memory usage of 30 GB due to the high amount of input data, the gridding process and high target matrix size. One volunteer was scanned using the vendor supplied 12-channel head coil in CP mode. The images in Fig. 1a and d were reformatted along a curved surface following the cranium in anterior-posterior direction (a) and along the teeth (d) to provide a panoramic overview. **Results** – Fig. 1a shows a reformatted slice along the cranium, illustrating the entire sagittal suture and its connections to the coronal and lambdoidal sutures. Figure 1b shows a sagittal view of the volunteer’s head, displaying excellent resolution and UTE typical signal in the skull and vertebra. The nasal cavity is free of susceptibility artifacts (1b and c), making fine internal structures clearly visible: The three layers of the conchae nasalis (arrows 1) and the compartments in the sinus ethmoidates (arrows 2). The sutures (1a, 1b arrows 3) of the skull are also delineated. Fig. 1d shows a reformatted slice mimicking a dental panorama view where the pulp canals are well described and even the dentin is depicted with some, albeit low, signal intensity. Fig. 1e is an oblique slice displaying the canalis mandibularis in the lower jaw bone.

**Discussion** – With scan time under 15 minutes a high resolution 3D data set of a human head was acquired with isotropic resolution of (0.53 mm)<sup>3</sup>. Due to the high oversampling of center k-space and the short echo time the reconstructed data set shows surprisingly good SNR despite the high spatial resolution, short repetition time and clinical field strength. Further improvements of SNR could be achieved at the cost of more measurement time by either averaging each readout or by increasing the number of spokes. The latter approach allows for flexible adjustment of measurement times, since spoke over- or under-sampling can be adjusted by an arbitrary factor. However, computational demands on the image reconstruction are currently rather high requiring computer hardware with at least 30 GB of memory.

**Conclusion** – With appropriate reconstruction hardware, 3D UTE radial center-out acquisition is a promising technique for performing high resolution isotropic imaging within moderate scan times. Due to the good SNR, robustness against motion artifacts and the readout oversampling the technique may not only be of interest for imaging short  $T_2$  tissue components. Especially high resolution imaging near anatomic areas typically affected by strong susceptibility artifacts (e.g., nasal cavities, oral cavity, and tracheae) could be promising applications. However, the heavy oversampling of the k-space center currently represents also one of the limitations of the technique: large matrices require huge amounts of readouts to fully sample 3D k-space. This disadvantage may, however, be alleviated in future implementations, since it has already been demonstrated that 3D radial acquisition bears a large potential for under-sampling [5,6].

**References** [1] Josan S et al., MRM 2009, 61:1083-1089; [2] Robson MD et al, NMR Biomed 2006, 19:765-780; [3] Proc Intl Soc Mag Reson Med 2012, #275; [4] Zwart NR et al., MRM, 2012; [5] Mistretta CA. JMIR 2009, 29(3):501-516; [6] Nam S et al. MRM 2012 (epub).

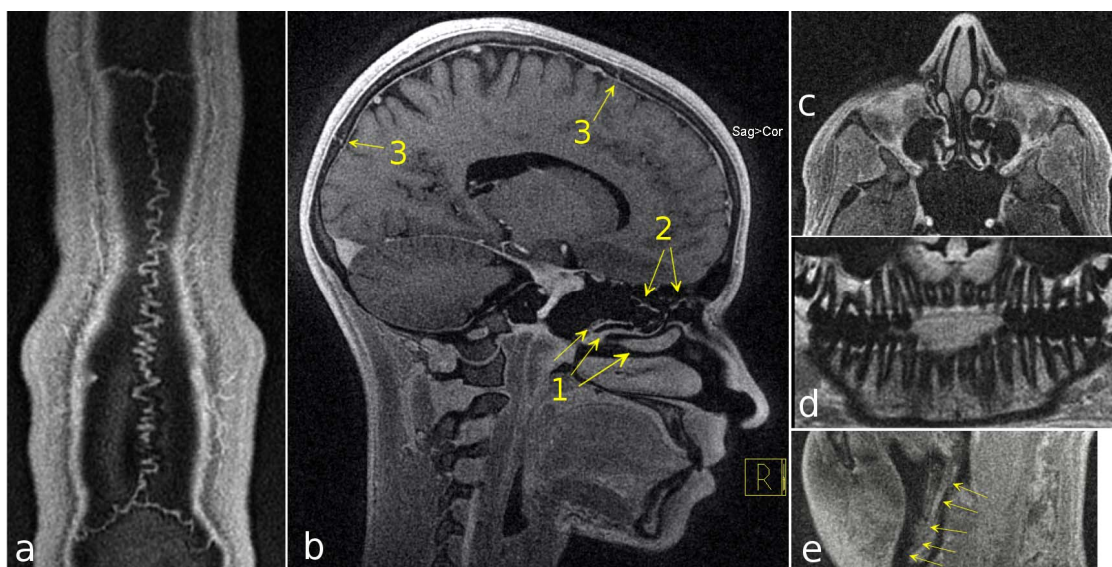


Fig 1: Different views of the same 3D volume UTE data set. (a) Curved reformatted slice displaying the sagittal suture. (b) Sagittal view of the full data set. The arrows mark the three conchae nasalis (1), sinus ethmoidates (2), and sutures (3). (c) Transverse view of the nasal cavities. (d) Curved reformatted view of the teeth, mimicking a dental panorama image. (e) Canalis mandibularis.