**Fast dynamic, high resolution contrast-enhanced MR angiography with CENTRA keyhole and SENSE**

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**Introduction:** In contrast-enhanced arterial MR angiography, there is often a quest for 3D sequences with high spatial resolution without venous enhancement. This can be obtained by starting to acquire phase-encodings in or near the center of k-space (elliptical centric [1] / CENTRA [2]). Nevertheless, these methods often produce an arterial image only and do not contain dynamic information. Additional dynamic information might provide insight about the filling of vessels. In this paper, a new method is presented which is designed to provide high spatial resolution angiograms with additional dynamic information at high temporal resolution.

**Methods:** The standard CENTRA [2] method acquires a central sphere in $k_yk_z$-space in a random order, followed by elliptical-centric readout of the periphery of k-space. The random filling of the middle of k-space is meant to avoid artifacts due to fast variations of the contrast agent. In the new keyhole-based method [3], *CENTRA keyhole*, the middle central sphere is repeated (n-1) times, and followed by an elliptical-centric readout of the periphery of k-space (see Fig. 1).

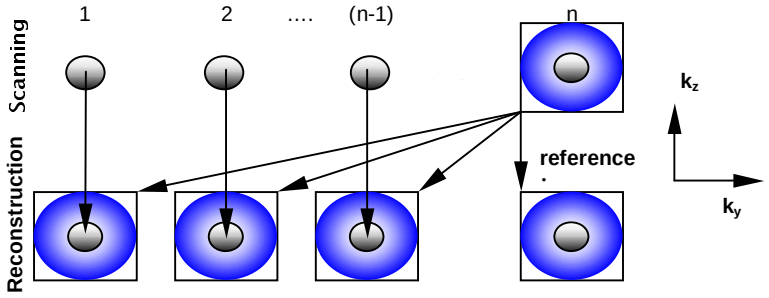


**Fig. 1**: CENTRA keyhole. Central sphere in $k_yk_z$ is randomly sampled and repeated (n-1) times, followed by a reference dataset with elliptical-centric readout of the periphery of k-space. The reference dataset is filled with each of the central spheres to finally reconstruct high-resolution dynamic datasets.

The CENTRA keyhole method was implemented on a clinical 1.5T MR system (Intera, Philips Medical Systems, Best, NL) and evaluated in five patients in the feet (n=4) and brain (n=1). Protocol description: 3D T1W gradient-echo, 300 sagittal slices x 1mm covering both feet, FOV 320, matrix 448x336, resolution 0.7x0.9x1.0 mm, TR/TE/flip = 4.4ms/1.4ms/25°, CENTRA keyhole with a 10-second central sphere repeatedly acquired 6 times. This provided six complete 3D datasets every 10 seconds. A 4-element SENSE body coil around the feet was applied. SENSE was used to further speed up the acquisition by a factor of 3. Total imaging time: 6x10s + 60s (reference) = 2 minutes. For the brain, a similar protocol was taken with 20 dynamic acquisitions of 0.5 seconds, reference scan 30 seconds. 20 ml of contrast agent was injected at 2 ml/s. The CENTRA keyhole scan was initiated before the arrival of the contrast using fluoroscopic triggering (BolusTrak).

**Results & Discussions:** All scans were performed successfully and 3D volumes with high-spatial and temporal resolution were obtained. An example of the dynamic feet scans is shown in Fig.2. Clear filling of the contrast agent can be seen, providing relevant dynamic information of the course of the contrast agent. The images contain crisp vessels without any artifacts possibly created by the transition of the central spheres and the reference dataset. We believe the random sampling contributes to a smoother transition. A speedup factor was reached of 10 (CENTRA keyhole) x 3 (SENSE) = 30. Even higher temporal resolution was obtained in the brain: 15x3=45.

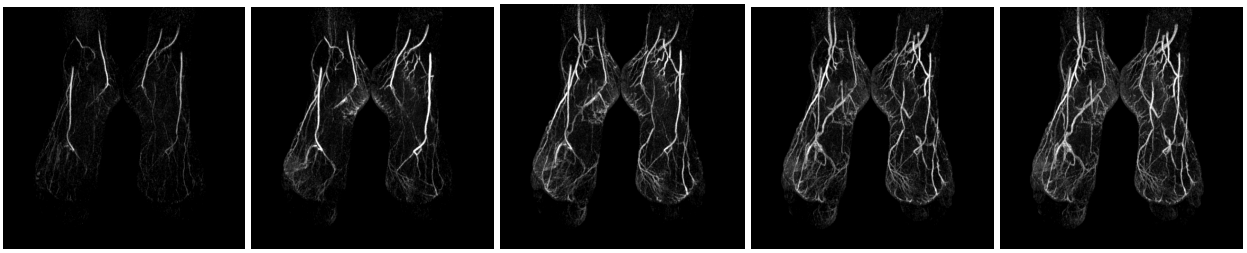

**Fig. 2**: CENTRA keyhole with SENSE in the feet, spatial resolution 0.7x0.9x1.0 mm, temporal resolution 10 seconds.

**Conclusions:** We have presented and successfully implemented a new method, CENTRA keyhole with SENSE, which enables contrast-enhanced 3D imaging with both high spatial and high temporal resolution. This was performed in the feet and in the brain, and speedup factors of 30 and 45 were obtained respectively. The new method does not produce any artifacts thanks to the random sampling of the phase-encoding steps. CENTRA keyhole is a very useful technique to provide additional dynamic information while maintaining high spatial resolution.

**References**: [1] Wilman et al. MRM 40:24-35 (1998), [2] Willinek et al. Radiology 225:583-588 (2002), [3] van Vaals et al. JMRI 3:671-675 (1993).