Combined Radial Acquisition and Regularized Reconstruction for Accelerated Vocal Tract Imaging

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Introduction: The performance of the structures involved in singing, especially regarding the patterns of the vocal tract during register changes have been frequently investigated in the past. MRI was found to be a very helpful imaging technique to directly visualize these structures. Nonetheless, only few studies provide quantitative results on such vocal tract changes in tenors or sopranos [1]. Even though the imaging speed of modern MRI systems has greatly increased over the last years, real time imaging is still a major challenge. Recent methods have employed non-Cartesian trajectories and iterative reconstructions, exploiting the spatial information of the receive coil arrays and including prior knowledge (compressed sensing) [2]. As previously reported, modern product sequences could be optimized to yield images at 8 frames per second, while still providing sufficient spatial resolution for quantitative analysis [1]. Since many vocal tract adjustments during singing are to be considered as very fast, there is a need for higher frame rates. It is our aim to improve the temporal resolution of imaging by means of a radial sampling pattern and an iterative reconstruction technique.

Methods: All images were acquired on a 3T Tim Trio system (Siemens, Erlangen, Germany) using the manufacturer's head and neck coil combination with 12 and 4 channels, respectively. For our experiment, the subject was asked to produce the sounds [ka] and [te] within a timespan of half a second. The correctness of the phrase was checked by an audio feedback system with an optical microphone (MR confon, Magdeburg, Germany). First, the previously reported Cartesian FLASH sequence of [1] was applied, providing sufficient spatial resolution with a temporal resolution of 125 ms (TR=2.6ms, TE=1.02ms, Flip Angle=5°, FOV 260x220x16mm3, Matrix=192x192, Grappa Factor=2). Second, an RF-spoiled radial gradient echo sequence was applied with a temporal resolution of 42 ms (TR=2.18 ms, TE=1.4 ms, FA=6°, FOV 190x190x6 mm3, Matrix=128x128, BW 1500 Hz/Pixel).

In radial acquisition, the k-space center is acquired with every shot, making it favorable for imaging of moving structures. Angular steps of $\varphi = 180° / [(\sqrt{5}+1)/2]) \approx 111°$ (golden angle) were chosen. This angle scheme provides a nearly optimal coverage of k-space for any given number of spokes [3], yet it also adds flexibility to the reconstruction, as the number of shots per image can be retrospectively chosen. This enables trading off temporal and spatial resolution. If less than $n_{shots} = \pi/2 * base\ resolution$ are used, the Nyquist criterion is violated in the periphery of k-space and the radius of the fully sampled circle around the k-space center is reduced.

In contrast to Cartesian sampling, radial sampling suffers from gradient delays. Before the actual measurement, we acquired several 360° sweeps of the object with a fine angular resolution and calculated the gradient delays from opposing shots with an autocorrelation method [4]. We used these calculated delays to do a zero and first order phase correction of all subsequently acquired raw data.

To reconstruct an image at a certain time point T_i of the measurement, a small number of shots in a time window around T_i are used to calculate low resolution coil sensitivity maps. Then, a regularized conjugate gradient SENSE-like method that employs the non-uniform FFT [5] was used for reconstruction. The imaging equation can be written as $S = Ax$, with the measured signal S and the forward operator A that includes the radial trajectory and coil sensitivities. The image x is then calculated by using a non-linear conjugate gradient to minimize the cost function $f(x) = \|Ax - S\|_2^2 + \lambda \|TV \cdot x\|_1$ where λ is the regularization parameter and TV the total variation operator [6]. The TV operator was chosen, as it emphasizes air-tissue boundaries. To further improve image quality and increase temporal resolution, a k-space weighted image contrast (KWIC) technique [3] was implemented. Here, a temporal window around T_i is defined. Only the two shots closest to T_i contribute data to k-space center. For the other shots in the temporal window, samples within a certain distance to the k-space center are removed. The radius of this elimination grows with increasing temporal distance. This prevents data from temporally distant shots to influence the image, while they still contribute to the high-frequency periphery of k-space and thus keep the spatial resolution high. In the presented study, sensitivity maps were calculated from 55 shots and 144 shots were processed by the KWIC-algorithm and used for the reconstruction of one image.

Results: The top row of Figure 1 presents images at four successive points in time sampled with the Cartesian sequence. These are compared with images of the radial acquisition from corresponding states of the vocal configuration. The red circles highlight regions that are blurred due to the long acquisition with the Cartesian FLASH sequence. Corresponding structures are also highlighted in the images acquired with the radial sampling.

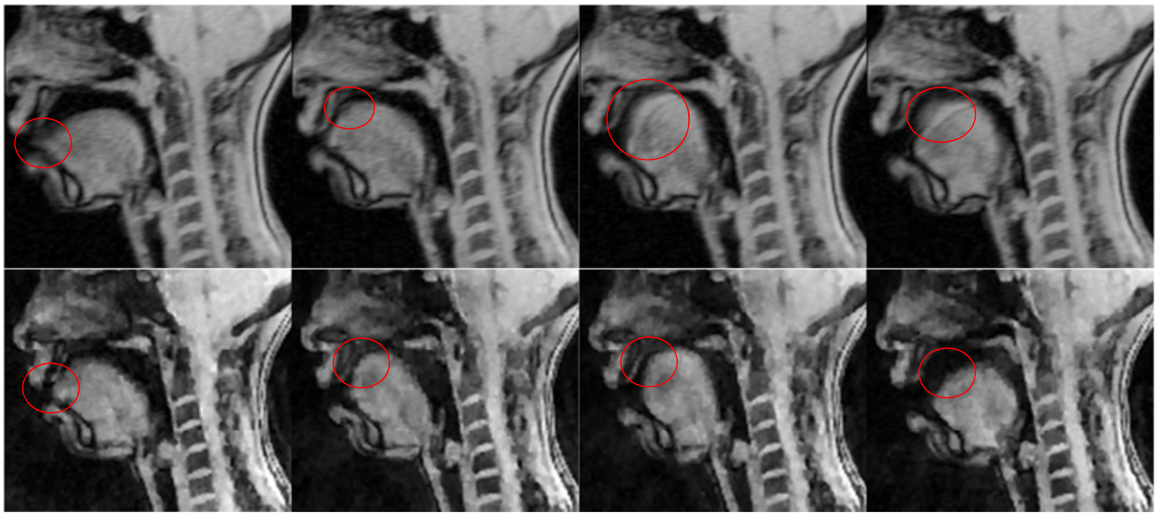

Figure 1. Top Row: Cartesian FLASH. Bottom Row: Radial FLASH. The regions of increased blurring are marked with red circles.

Discussion: In our images, blurring that is induced by long acquisition windows is reduced by combining radial sampling and a regularized reconstruction. Our approach is still limited by the low quality of the sensitivity maps and the large and adversely distributed receiver coils. However, the quality and temporal fidelity is sufficient to study changes of the vocal tract in singers.

References: [1] Echternach M, et al., J Voice, 2011 (in press). [2] Niebergall et al., MRM 2012 (in press). [3] Winkelmann et al., IEEE Trans Med Imaging, 2007, 26:68-76. [4] Ahn C B, IEEE Trans Med Imaging, 1987,6(1):32-6. [5] Fessler J, et al., IEEE T Signal Proces 2003,51:560–574. [6] Rudin L, Physica D, 1992,60:259–268.

Acknowledgments: This work was supported by DFG grant #RI 1050/4-1 and ERC #232908 as part of the OVOC project.