Improved 3D MR imaging using virtual coil deconvolution for effective density weighted imaging (VIDED)

M. Gutberlet[1], A. Roth[1], D. Hahn[1], and H. Köstler[1]
[1]Institut fuer Roentgendiagnostik, University of Wuerzburg, Wuerzburg, Bavaria, Germany

Purpose: 3D-MRI suffers from long scan times due to the additional phase-encoding in slice direction becoming a severe problem in dynamic imaging like dynamical 3D-MR mammography. Theoretically, the FOV in slice direction, defined by the sampling density in slice direction, could be restricted to the homogeneously excited slab. However, because of the non-rectangular shape of the excited slab the FOV has to be increased in order to avoid aliasing. This leads to a loss of resolution or in an increase of the scan time. Therefore, in practice aliasing in the outer slices is tolerated in favor of an increase of resolution. Additionally, the typically low number of phase-encoding samples results in immense Gibbs-artifacts. Filtering can be used to suppress these artifacts, but leads to a reduced SNR and a loss of resolution. For example, a Hanning window reduces the SNR to $\sqrt{2/3} \approx 81\%$. Purpose of this work was to apply a new sampling and reconstruction method enabling an increased FOV, a reduction of Gibbs-artifacts at optimal SNR and a reduction of the slice thickness without a lengthening of the scan time compared to conventional Cartesian sampled 3D imaging.

Methods and material: In contrast to filtered Cartesian imaging, density weighted (DW) imaging [1] acquires k-space with a sampling density proportional to the desired window function. Since all data are weighted equally in reconstruction, Gibbs-artifacts are suppressed without a loss of SNR. However, in fast imaging, because of the varying sampling density the Nyquist criterion is violated in the outer parts of k-space resulting in incoherent aliasing (see spatial response function (SRF) in Fig.1, bottom). The undersampled data may be reconstructed by parallel imaging, but is limited to imaging with multi coil arrays [2]. In this work, DW samplings with Hanning shaped sampling density were calculated with a minimum sampling density of 0.5 limiting the amount of aliasing (Fig.1). A slight filter was applied at k-space positions where the density differed form the desired window function. This reduces the SNR gain of DW form 23% to 17%. The DW data were reconstructed with the conventional convolution gridding and a method called **v**irtual co**i**l **d**econvolution for **e**ffective **d**ensity weighted imaging (**VIDED**). In virtual coil imaging [3], a virtual coil is generated by conjugation and mirroring of the k-space of the actual coil. The undersampled parts of k-space are reconstructed with a k-space based non-Cartesian parallel imaging algorithm [4] using the actual and virtual coil as a coil array. VIDED allows the reconstruction of twofold undersampled data even with a single receiver coil. In contrast to conventional parallel imaging, the sensitivities of the different coils solely differ in their phase. Therefore, VIDED is a phase constrained method. Calibration is done from a low resolution phase map derived from the Nyquist sampled central part of k-space. VIDED is a parallel imaging method and consequently may enhance the noise in the reconstruction which is described by the geometry (g-) factor. It was shown, that sampling k-space asymmetrically [3] minimizes the g-factor. Therefore, DW asymmetric samplings with $k_{max,DW} = k_{max,Cart}$ and $k_{max,DW} = 1.3k_{max,Cart}$ were applied in 3D phantom and 3D dynamic contrast enhanced MR-mammography studies. For comparison, Cartesian sampled data with the same number of phase-encoding steps were acquired. A Hanning-shaped k-space filter was applied to the Cartesian data. The SRFs of filtered Cartesian, gridded DW and VIDED were measured in the phantom study from a sharp edge. SNR maps were calculated by the method proposed by Robson et al. [5].

Results: The central part of the SRFs provided by the phantom study are identical within the experimental errors for filtered Cartesian, gridded DW and VIDED. In comparison to filtered Cartesian imaging, gridded DW and VIDED show an increased FOV in slice direction (Fig.2). For $k_{max,DW} = k_{max,Cart}$ the magnitude images of gridded DW provide only slight aliasing artifacts, while the complex images are significantly corrupted by incoherent aliasing. In VIDED imaging, neither the complex nor the magnitude images provide any visible aliasing. The SNR calculations of gridded DW provided a homogeneous SNR gain of 17% compared to filtered Cartesian imaging. In VIDED imaging, the mean SNR gain is reduced to 15%. The mean g-factor was 1.02 and shows very low spatial variation. For the acquisition of thinner slices (Fig.3), i.e. $k_{max,DW} = 1.3k_{max,Cart}$, the aliasing artifacts of gridded DW are significantly increased. In VIDED imaging these artifacts are suppressed. However, the noise maps show increased, but still low spatial variation with a mean g-factor of 1.08.

Discussion: Asymmetrically sampled DW acquisition schemes and a novel reconstruction method were presented allowing a significant improvement of 3D-MRI. The DW sampling of k-space reduces the Gibbs-artifacts at an optimal SNR. Limiting the minimum sampling density to 0.5 reduced the aliasing by undersampling of the k-space edges (Fig.1) at the expense of a small SNR reduction. Gridded DW provided very low artifacts in the magnitude images, although the complex images showed significant incoherent aliasing. The asymmetric sampling of k-space and the very low variation of the image phase result in an orthogonal phase between image and aliasing. Therefore, the aliasing, having much lower amplitude than the image for the DW sampling (see SRF in Fig.1), adds with minimum contribution in direction of the image. For $k_{max,DW} = 1.3k_{max,Cart}$ the slice resolution is improved without a lengthening of the scan time resulting in increased aliasing due to the increase of undersampling. VIDED reduces aliasing effectively for both samplings. However, while for $k_{max,DW} = k_{max,Cart}$ almost the complete SNR improvement of density imaging can be achieved, for the high resolution case the high image quality in VIDED is achieved only with an average SNR gain of 1.08%.In contrast to the pixelwise superposition of undersampled Cartesian imaging, in DW imaging the non-Cartesian acquisition results in incoherent undersampling artifacts (see SRF in Fig. 1, bottom) distributing the aliasing over the whole FOV. This can be used to increase the FOV in slice direction up to 25%.

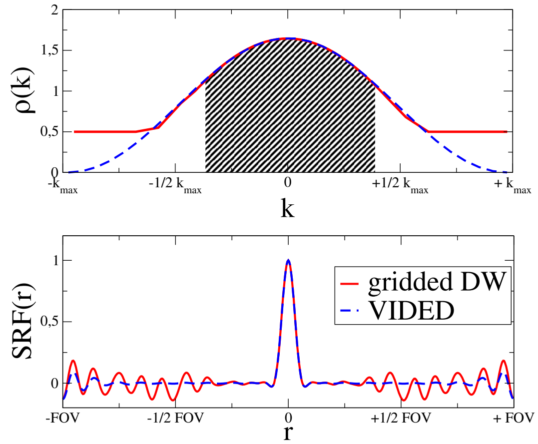

Figure 1: DW samping scheme (red line) used for the acquistion of k-space. The black shaped area indicates the Nyquist sampled k-space and the blue line the Hanning window. The corresponding SRF of gridded DW shows incoherent aliasing, which is suppressed in VIDED imaging.

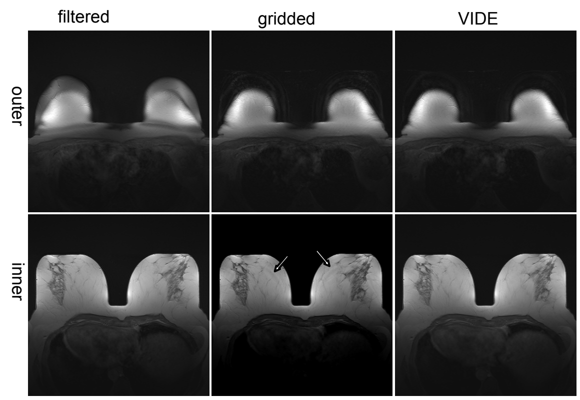

Fig.2: Results of the mammography for filtered Cartesian, gridded DW and VIDED imaging. The upper images show a slice at the outer part of the 3D block, while the bottom row shows a slice in the center. In Cartesian imaging the outer slice shows massive aliasing due to the undersampling in slice direction, which is drastically reduced in VIDED and gridded DW due to the non-Cartesian sampling. In contrast to VIDED, gridded DW shows low aliasing (indictate by the arrows) from the undersampling at the k-space edges.

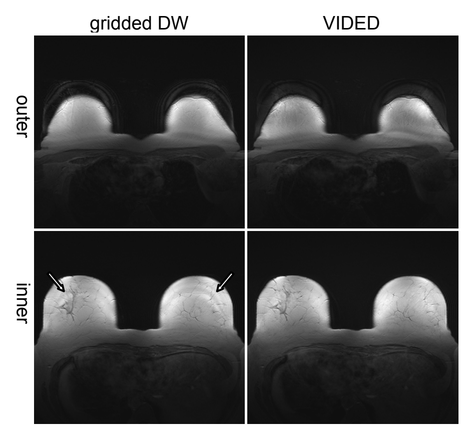

Fig.3: The results of the mammography with thinner slices. Due to the increased undersampling the aliasing is increased in gridded DW, but disappears in VIDED.

References: [1] Greiser et al. MRM 50(6), 1266-1275 (2003) [2] Geier et al. MAGMA 20, 19-25 (2007) [3] Blaimer et al., MRM61(1), 93-102 (2009) [4] Yeh et al., MRM 55(6), 1383-1392 (2005) [5] Robson PM et al, MRM 60:895-907 (2008)