Highly accelerated quantitative flow measurements using *k-t* SENSE with large coil arrays

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INTRODUCTION In recent reports, it was demonstrated that phase-contrast (PC) flow measurements can be accelerated using the *k-t* SENSE approach [1-2]. However, temporal low-pass filtering occurring at high acceleration factors compromised the accuracy of flow quantification. To address this drawback, a large number of receiver coils might be used. The impact of large coil arrays on the temporal fidelity of the *k-t* SENSE reconstruction was recently investigated for anatomical images [3]. Since PC measurements have specific requirements as to the accuracy of the phase information, the aim of this work was to investigate the impact of using such large coil arrays on the accuracy of *k-t* SENSE accelerated flow measurements. For this purpose, a fully sampled reference dataset was acquired. A subset of these data was used to simulate 16-fold accelerated PC flow measurements. It is demonstrated that the accuracy of *k-t* SENSE accelerated quantitative flow measurements improves when using a larger number of coil elements.

METHODS In the *k-t* SENSE approach [1], the data collection is accelerated by undersampling *k-t* space, where *k* and *t* denote the spatial frequency and time, respectively. To resolve aliasing in the corresponding *x-f* space, with *x* and *f* denoting space and temporal frequency, respectively, low-resolution training data are used as prior knowledge of the signal distribution, in conjunction with the sensitivity information of the receiver coils. The amount of training to be acquired is determined by a trade-off between overall scan duration and resolution of the training data. The dependency of the reconstruction error on the resolution of the training data was investigated by Hansen et al. [4] for typical cardiac applications. Rather than increasing the resolution of the training data, one may choose to use a larger number of receiver coils to improve the reconstruction accuracy to not prolong scan times.

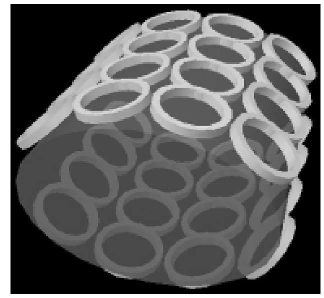

Figure 1. Prototype phased-array coil consisting of 32 coil elements and covering 320 mm in feet-head direction.

A fully sampled cine PC dataset was acquired in the ascending aorta of a healthy volunteer using a 32 channel phased-array prototype coil (Fig. 1). Scan parameters were: FOV: 330x217x10 mm³ resolution: 1.3x1.3x10 mm³, TE/TR: 4.5 / 8.8 ms, venc: 150 cm/s, 32 cardiac phases. Three acquisitions were averaged to reduce respiratory motion artifacts. A subset of the data was used to simulate 16-fold accelerated *k-t* SENSE acquisitions using 5 training profiles resulting in a net acceleration factor of 11.2. Simulations were repeated for an increasing number of coil elements, where the elements were selected in descending order of their sensitivity. To investigate the performance of the *k-t* SENSE reconstruction, accelerated ($a_{x,y,t}$) and reference ($r_{x,y,t}$) acquisitions were compared by calculating the relative RMS error of the complex data ($RMS_{complex}$) and of the phase maps (RMS_{phase}) as defined by:

$$RMS_{complex} = MEAN_t\left(\sqrt{\frac{\sum_y^{N_y}\sum_x^{N_x}\left[a_{x,y,t}-r_{x,y,t}\right]^2}{\sum_y^{N_y}\sum_x^{N_x}\left[r_{x,y,t}\right]^2}}\right) \qquad RMS_{phase} = MEAN_t\left(\sqrt{\frac{\sum_y^{N_y}\sum_x^{N_x}\left[\frac{\|a_{x,y,t}\|+\|r_{x,y,t}\|}{2}*\angle\left(r_{x,y,t}*conj\left(a_{x,y,t}\right)\right)\right]^2}{\sum_y^{N_y}\sum_x^{N_x}\left[\frac{\|a_{x,y,t}\|+\|r_{x,y,t}\|}{2}*\angle\left(r_{x,y,t}\right)\right]^2}}\right)$$

Furthermore, the flow curves evaluated in the ascending aorta were investigated with respect to accurate flow values and temporal fidelity.

RESULTS Figure 2 shows the fully sampled reference dataset and the 16-fold accelerated *k-t* SENSE dataset using all 32 coil elements. The *k-t* SENSE accelerated dataset reveals image quality comparable to the reference dataset. A good agreement of both datasets was found for a spatio-temporal plot crossing the ascending aorta.

Figure 3a shows flow curves evaluated from the reference dataset and from 16-fold accelerated *k-t* SENSE reconstructed images using 5 to 32 coils. Overall, a good agreement of the flow curves is observed. Improved accuracy can be seen during peak systolic (Fig. 3c) and retrograde flow (Fig. 3d). The accuracy of the reconstruction improved for both the $RMS_{complex}$ and the RMS_{phase} for an increasing number of coils (Fig. 3b).

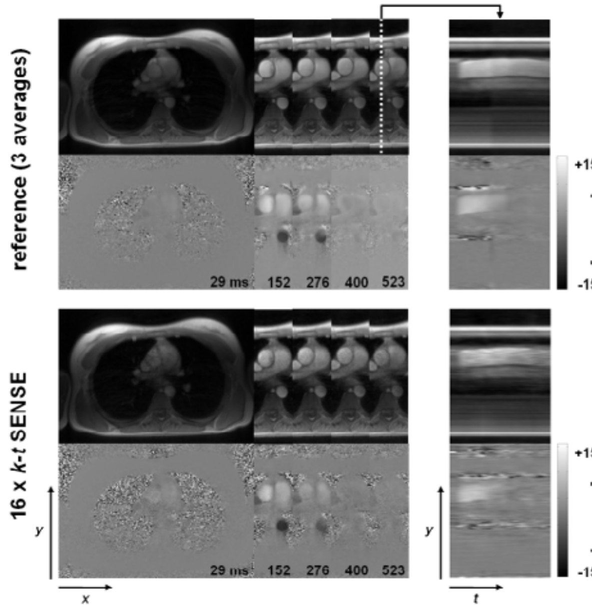

Figure 2. Anatomical images and phase maps of five cardiac phases. On the right: Spatio-temporal plot of a column (dotted line) crossing the ascending aorta; Top row: Fully sampled reference data using 32 coils; Bottom row: 16-fold accelerated *k-t* SENSE data using 32 coils.

DISCUSSION In this work, the impact of large coil arrays on the accuracy of *k-t* SENSE accelerated flow measurements was investigated.

In computer simulations, it was demonstrated that the accuracy of 16-fold accelerated *k-t* SENSE acquisitions can be improved using a larger number of coil elements. The relative RMS error of the complex data decreased for an increasing number of coils. The very slight increase of the relative RMS error of the phase maps for 24 and 32 coil elements might be explained by a non-optimal estimation of the coil sensitivity maps due to poor signal-to-noise ratios of the coil elements far away from the imaging slice. Thus, optimizing the coil design might result in further improvements for 2D cardiac applications.

The application of large coil arrays holds promise to improve the accuracy of *k-t* SENSE accelerated flow measurements and might enable even higher acceleration factors. At lower acceleration factors, the use of a large number of coil elements might allow for the acquisition of fewer training profiles and thus shorter scan time.

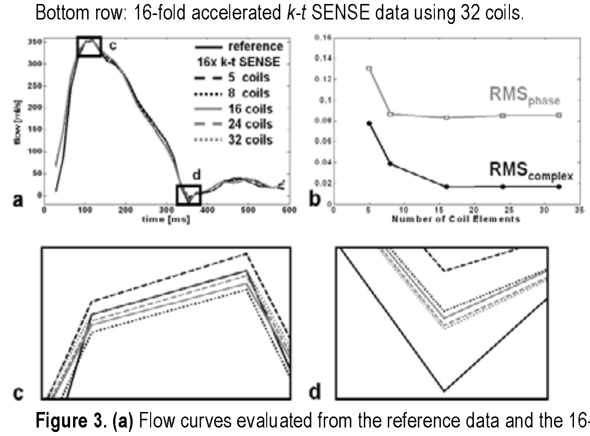

Figure 3. (a) Flow curves evaluated from the reference data and the 16-fold accelerated *k-t* SENSE data using 5 to 32 coils. **(b)** RMS error of the complex data and the phase maps for increasing coil elements. **(c), (d)** Details of the flow curves as indicated by the black boxes.

REFERENCES [1] Tsao J et al. Magn Reson Med 2003. 50 (5):1031-1042; **[2]** Baltes C. et al. Proc. ISMRM 2005, 383, **[3]** Kozerke S, Proc. ISMRM 2005, 2452, **[4]** Hansen M. S. et al. Magn Reson Med 2004 52 (5): 1175-83