RAPID ACQUISITION OF PET ATTENUATION MAPS FROM HIGHLY UNDERSAMPLED UTE IMAGES USING SPARSE-SENSE RECONSTRUCTION

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Introduction: Attenuation correction (AC) maps are required for accurate PET reconstruction. High resolution AC-maps are needed to depict bone precisely, especially for osseous lesions and for cranial imaging[2]. It has been shown that segmented AC-maps can be obtained from ultrashort echo time (UTE) MR imaging[1]. However, clinical use of UTE in simultaneous PET/MR is limited by the long scan time (more than 7 min) needed to achieve the high spatial resolution of small bone structures. Recently it has been shown that single-echo UTE imaging can be accelerated with compressed sensing (CS)[3,4] or a combination of CS and SENSE (Sparse-SENSE) reconstruction[5]. In this study we show that high resolution AC-maps can be obtained from 8x prospectively undersampled dual-echo UTE using Sparse-SENSE, with accuracy comparable to those produced from fully sampled acquisitions.

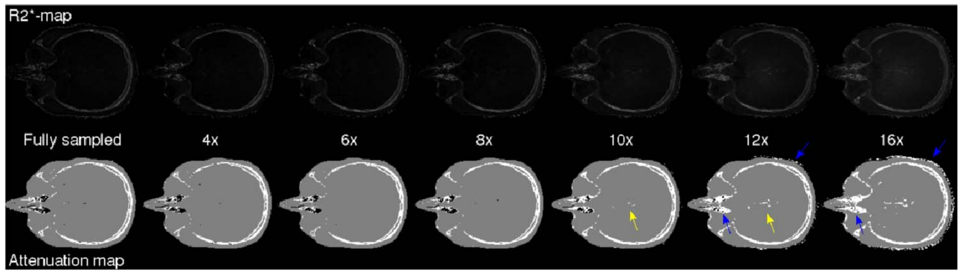

Fig. 1 R_2* maps and PET attenuation correction (AC) maps derived from fully sampled and retrospectively undersampled UTE data. There is good agreement between the fully sampled and undersampled maps with undersampling factors of up to 8. Beyond this, contrast between bone and soft tissue deteriorates in the R_2^* maps and regions of soft tissue become misclassified as bone in the AC-maps (yellow arrows). Smoothing at air-tissue boundaries, such as in the sinuses and around the skin also leads to misclassification at higher undersampling factors (blue arrows).

Methods: *Acquisition:* Dual echo UTE scans ($TE_1/TE_2/TR$ = 0.14/2.41/4.7 ms, FOV = 250 mm diameter, voxel size = 1.25mm isotropic) were acquired of the heads of healthy volunteers using a 3D radial acquisition on a 3T system (Philips, Best, NL), with an 8 channel head coil and corrected for eddy currents using a dynamic field camera (Skope LLC, Zurich, CH).
Simulations: To investigate undersampling limits, fully sampled images (w.r.t. Cartesian sampling: 80,000 projections, acq. time 7.5 min) were acquired of one volunteer and retrospectively undersampled (4, 6, 8, 10, 12 and 16x).
Prospective undersampling: According to simulation results, 8x prospectively undersampled (acq. time 53 s) images were acquired of 5 volunteers and compared to fully sampled acquisitions. *Reconstruction:* Fully sampled images were reconstructed using gridding. Both undersampled echo images were reconstructed independently by minimizing $J(\mathbf{m}) = ||\mathbf{Em} - \mathbf{y}||_2 + \lambda\, ||X\mathbf{m}||_1$, where **m** is the reconstructed image, **y** is the k-space data, **E** is the encoding operator that incorporates the coil sensitivities and undersampled Fourier operator, **X** is the finite difference operator and λ is a regularization term. Coil sensitivity maps were estimated from the fully sampled k-space center of the data from the first echo. *Segmentation:* Images were segmented using the approach described in [1], with the addition of automatic threshold selection using k-means clustering[6]. In short, air is segmented from bone and soft tissue using the first echo. Bone and soft tissue are then segmented using an R_2* map, calculated as $R_2^* = (\ln|I_1| - \ln|I_2|) / (TE_2 - TE_1)$, where I_1 and I_2 are images acquired at TE_1 and TE_2.

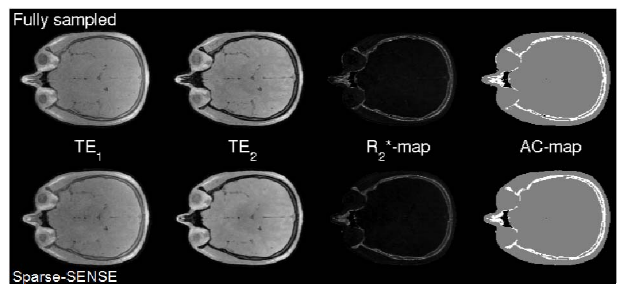

Fig. 2 Top row: Fully sampled UTE image showing signal from bone, echo image acquired after decay of bone signal, R_2^* map and segmented PET attenuation map. Bottom row: as above with 8x prospective undersampling and reconstruction Sparse-SENSE. There is good agreement between AC-maps generated from the undersampled and fully sampled data. Fine bone structures such as in the orbits are well resolved in the Sparse-SENSE maps.

Results: *Simulations:* R_2* and AC maps derived from retrospectively undersampled data are shown in Fig.1. There is good agreement with the fully sampled case up to a factor of 8x undersampling. Beyond this, contrast between bone and soft tissue decreases in the R_2^* maps and misclassification occurs in the AC-maps (arrows). At 8x undersampling the percentage of correctly classified pixels compared to the fully sampled case was 97% (in air, bone or soft tissue).
Prospective undersampling: UTE images, estimated R_2^* maps and AC-maps derived from fully sampled and 8x prospectively undersampled acquisitions are shown in Fig.2 for a particular volunteer. There is good agreement between the fully sampled and undersampled Sparse-SENSE reconstructions. Small bone structures around the orbits are clearly seen in the Sparse-SENSE derived R_2^* maps and are successfully segmented in the AC-map. Orthogonal slices from a different volunteer are shown in Fig.3, showing a good agreement in all three orientations. The mean correct pixel classification across all volunteers was 96 ± 0.4 % relative to the fully sampled case.

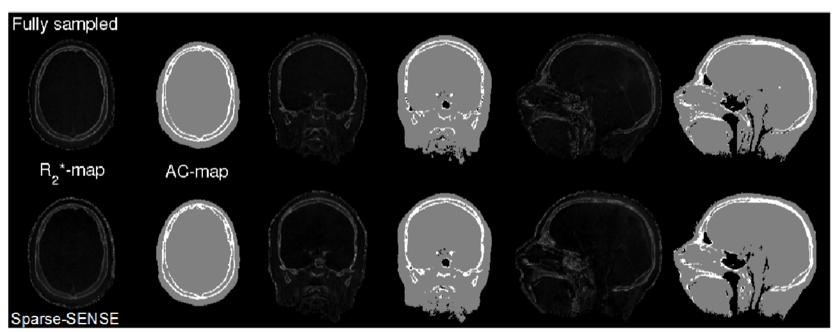

Fig. 3 Axial, coronal and sagittal slices of fully sampled and 8x prospectively undersampled R_2^* maps and derived PET attenuation correction (AC) maps. The agreement between the fully sampled and Sparse-SENSE AC maps is good and fine structures are segmented correctly in the undersampled maps.

Discussion: We have shown that segmented PET-AC maps can be calculated from highly undersampled UTE-scans, with accuracy comparable to those produced from fully sampled scans. As a result, high resolution attenuation map of the head can be acquired in less than one minute. In future work, further acceleration by exploiting sparsity in the R_2* maps will be investigated.

References: [1] Keereman et al. 2010 J. Nucl. Med. 51:812-818, [2] Martinez-Möller et al. 2009, J. Nucl. Med. [3] Lustig et al. 2007 MRM 58:1182-1195, [4] Li et al. 2012 ISMRM 20:1402, [5] Johnson 2012 ISMRM 20:285, [6] Aitken et al. 2011 BC-ISMRM.