# IMPROVED MOTION COMPENSATED RECONSTRUCTION FOR 3D ABDOMINAL MRI USING A SELF-NAVIGATED NON-RIGID MOTION MODEL

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**INTRODUCTION:** Respiratory motion remains a major challenge in 3D abdominal MRI, introducing ghosting and blurring. Respiratory gating can reduce these artifacts, but leads to long scan time due to low scan efficiency. Alternatively, non-rigid abdominal motion may be estimated from undersampled respiratory resolved images and corrected during reconstruction[1]. This approach, so-called TV-GMD inter-bin, groups free-breathing data into respiratory positions (bins), obtains a non-rigid motion model via registration and corrects for the estimated inter-bin motion during the reconstruction (Fig1a). However, intra-bin motion is unaccounted for resulting in (potentially considerable) residual motion artifacts, particularly in end-inspiration where large bin windows are required to ensure enough data for reconstruction. Moreover, motion estimation accuracy is limited in poorly populated regions of the respiratory cycle (typically end-inspiration or due to drifts in the breathing pattern) and some data may be discarded. Here, we propose an intra-bin motion correction approach to further improve the accuracy of TV-GMD inter-bin. This approach is based on the assumption of a linear relation between the non-rigid motion of each acquired data within the bin and the inter-bin non-rigid motion model. The proposed TV-GMD intra-bin correction (Fig1.b) is compared with the inter-bin motion correction approach and the conventional gated reconstructions, showing significantly improved sharpness and image quality in 3 healthy volunteers.

**METHODS:** Data is acquired using a self-navigated GRPE (golden radial phase encoding) trajectory[2], allowing data to be grouped into different respiratory bins (Fig.1a). These undersampled bins are reconstructed with total variation (TV) regularized iterative SENSE[3] and registered[4] to estimate inter-bin motion ($U_b$). We propose that intra-bin motion at the respiratory position $p$ ($U_p$) may be obtain by scaling the non-rigid inter-bin motion fields: $U_p = \beta_p U_{b_i}$ (Fig1.b). Here, we use the respiratory signal to determine the scaling factor $\beta_p$ according to the relative distance between acquired data $p$ and its corresponding bin: $\beta_p = (\Delta p - \Delta b)/\Delta b$, where $\Delta b$ is the distance between the mean positions of bin $i$ ($\bar{b}_i$) and end-exhale bin ($\bar{b}_{ex}$), $\Delta p$ is the distance between $\bar{b}_{ex}$ and $p$. Thus, a motion model $U_p$ with higher temporal sampling than $U_b$ is obtained per acquired data point (intra-bin). In particular, this model $U_p$ provides accurate motion estimation in the extreme points of the respiratory cycle, which was previously unavailable. Finally, the estimated intra-bin motion $U_p$ is incorporated into a TV regularized general matrix description[5] reconstruction (TV-GMD), correcting 3D non-rigid abdominal motion directly in the reconstruction of the complete dataset. This is done by solving $\hat{\boldsymbol{I}} = arg\ min_{\boldsymbol{I}}\{\|\boldsymbol{EI} - \boldsymbol{K}\|_2^2 + \boldsymbol{\lambda}_s \boldsymbol{TV}_s\}$, where $\boldsymbol{E}$ is the generalized encoding matrix (includes the Fourier operator, coil sensitivities, the sampling operator and the intra-bin motion fields $U_p$), $\boldsymbol{I}$ is the ideal image, $\boldsymbol{K}$ the acquired data, $\boldsymbol{TV}_s$ is spatial total variation and $\boldsymbol{\lambda}_s$ the regularization parameter.

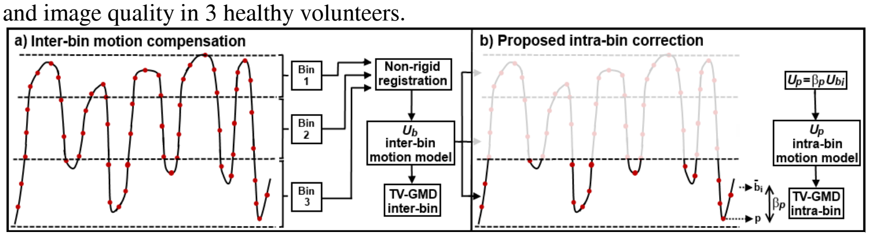


**Fig.1: a)** Acquired data is grouped into respiratory bins, non-rigid motion is estimated between them (*$U_b$*) and this inter-bin motion is corrected with TV-GMD. **b)** Schematic of intra-bin correction for Bin 3: intra-bin non-rigid motion (*$U_p$*) at arbitrary respiratory positions can be obtained by scaling the estimated $U_b$ with $\beta_p$ and corrected with TV-GMD.

**EXPERIMENTS:** So far three healthy volunteers were scanned free-breathing on a 1.5T Philips scanner using a 32 channel coil (b-SSFP, FOV = 287mm isotropic, resolution = 1.75mm isotropic, *TR/TE* = 3.0/1.4ms, flip angle = 30°, radial undersampling = 2). Three reconstructions were performed from the same acquired data: a 5mm gated reconstruction, inter-bin TV-GMD and the proposed intra-bin TV-GMD. Methods were compared using measures of vessel sharpness (VS), liver sharpness (LS) and visual image evaluation of ghosting and blurring on a scale of 1 (severe ghosting/blurring) to 4 (no ghosting/blurring) by 4 experts.

**RESULTS:** Reconstruction results for respiratory gated, TV-GMD inter-bin and the proposed TV-GMD intra-bin are shown in Fig.2. The respective measures (normalized to the gated) obtained were: VS = 1.00±0.17, 1.12±0.18 and **1.28±0.19**; LS = 1.00±0.08, 1.37±0.09 and **1.65±0.08**; visual evaluation = 1.17±0.33, 2.60±0.47 and **3.56±0.40**. Both TV-GMD approaches had a scan efficiency of 100±0%, whereas the gated had 64±5%.

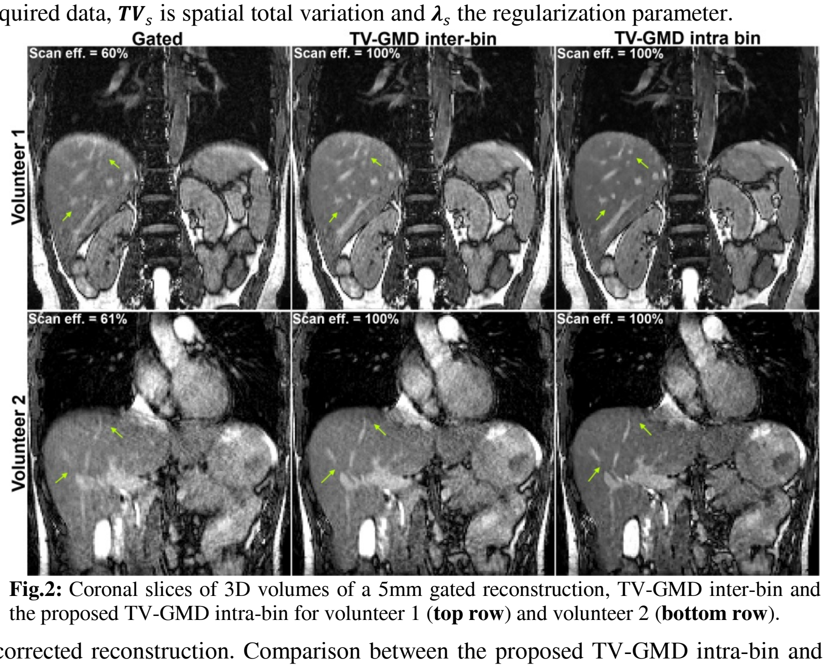


**Fig.2:** Coronal slices of 3D volumes of a 5mm gated reconstruction, TV-GMD inter-bin and the proposed TV-GMD intra-bin for volunteer 1 (**top row**) and volunteer 2 (**bottom row**).

**CONCLUSION:** We have proposed a simple intra-bin motion model to further improve image quality of abdominal motion corrected reconstruction. Comparison between the proposed TV-GMD intra-bin and TV-GMD inter-bin shows a significant improvement of ~14% in VS, ~20% in LS and ~37% in visual evaluation of ghosting/blurring. Further work will focus on improving motion estimation in undersampled datasets and validating the proposed model in additional subjects.

**REFERENCES:** [1] Cruz et al, ISMRM 2013; [2] Prieto et al, MRM 2010; [3] Lustig et al, MRM 2007; [4] Buerger et al, *MedIA* 2011; [5] Batchelor et al, MRM 2005.