# Simultaneous Multi-Slice accelerated 4D-MRI for the Unity MR-linac

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## Introduction

- 4D-MRI (3D volume + respiratory phase) is increasingly important for simulation and daily guidance of thoracic and abdominal radiotherapy.
- Slice-based 4D-MRI offers many benefits (e.g. contrast flexibility, image-based self-navigation), but struggles to cover the entire field-of-view in a time-efficient manner.
- Simultaneous multi-slice (SMS) is a mature technique to accelerate slice-based MRI acquisitions.
- This study exploits the SMS technique to accelerate the acquisition of a balanced turbo-field echo (bTFE) coronal 4D-MRI sequence on the 1.5 T Unity MR-linac (Elekta AB, Stockholm, Sweden).

## Method

- We developed an SMS-accelerated single-shot bTFE sequence for the MR-linac based on a stack of 52 coronal 2D images acquired repeatedly over 30 dynamics in an interleaved order.
- Simultaneously excited slices were separated by half the FOV.
- Motion of the liver dome in the craniocaudal (CC) direction was used to derive an image-based self-sorting signal (van de Lindt et al, 2018, IJROBP).
- Slices were sorted into 10 amplitude bins, and the temporal relationship of simultaneously excited slices was used to generate sorted 4D-MRIs for 6 healthy volunteers.
- The self-sorting signal was validated using the Quasar MRI4D (ModusQA, London, ON, Canada) motion phantom.
- The through-plane liver dome smoothness of the sorted 4D-MRIs were quantified in terms of root-mean-square deviation (RMSD) by using a third order polynomial fit.

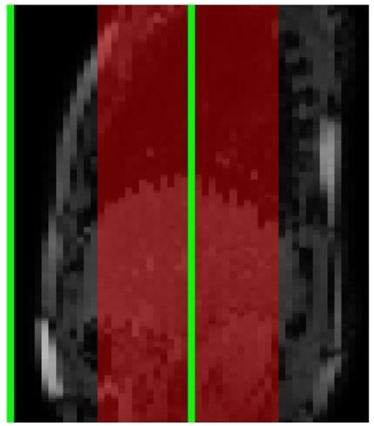

***Figure 1:*** *A sagittal cut through the liver for the first dynamic. The red rectangle identifies the navigator slices, which are used for the self-sorting signal. The green color pair shows simultaneously acquired slices that were shifted by half the FOV.*

## Scan parameters

- FOV: 30(CC)x45(LR)x26(AP)cm$^3$
- Resolution: 2x2x5mm$^3$
- Image matrix: 240x240x52
- SMS: 2
- SENSE: 2.5
- TR/TE: 3.86/1.93ms

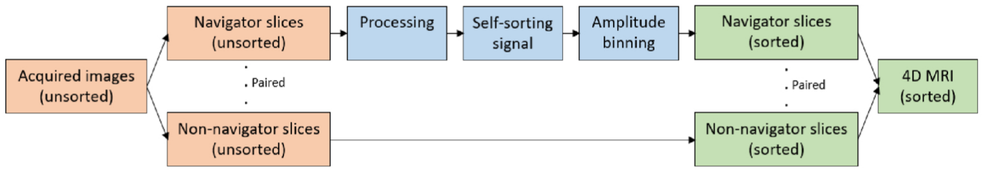


***Figure 2:*** *Schematic representation of the reconstruction workflow of our novel SMS-4D-MRI sequence.*

## Results

- Acquisition time of 5 minutes.
- Reconstruction time within 1 minute.
- The peak-to-peak (SD) motion in the sorted 4D-MRIs of the volunteers was between 11.3-20.6 (3.4-7.5) mm. Motion extracted from the corresponding self-sorting signals agreed within 1.9 (0.7) mm.
- In the phantom, the self-sorting signal showed a high correlation with the sinusoidal motion signals (≥0.98).
- The average RMSD of the liver dome smoothness was in the range of 1.1-2.1 mm.

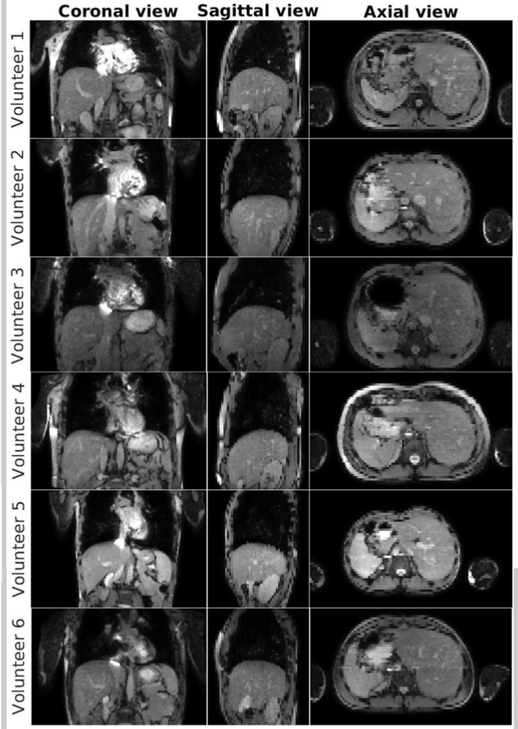


***Figure 4:*** *Reconstructed SMS-4D-MR images (end-exhale shown). Note that the arms are partly invisible due to REST slabs placed outside the body contour.*

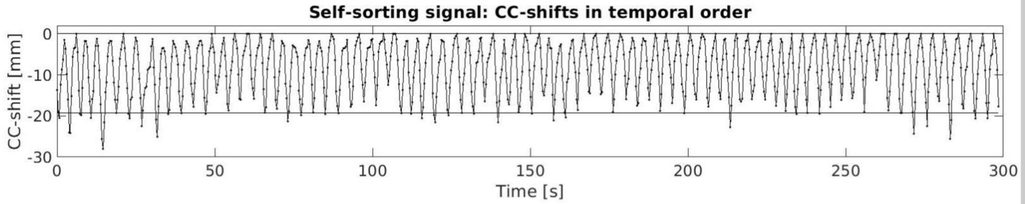


***Figure 3:*** *Exemplary image-based self-sorting signal. The two horizontal lines indicate the 95% data inclusion range.*

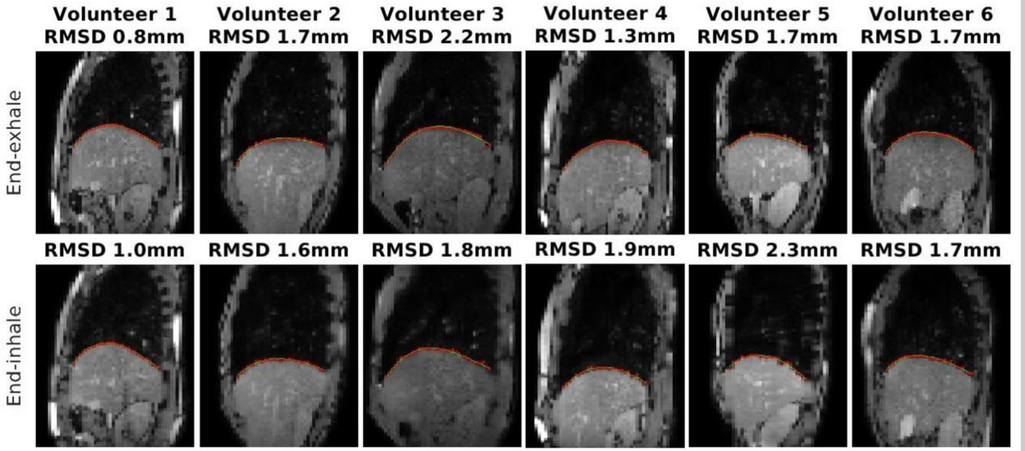


***Figure 5:*** *Sagittal cut through the liver for the end-exhale and end-inhale phases. On top is the liver dome smoothness quantified in terms of root-mean-square deviation (RMSD), using a third order polynomial fit (green) through the liver dome locations (red).*

## Conclusions

The SMS-4D-MRI sequence yields anatomically plausible 4D representations and is thus a strong candidate for daily MR-guided radiotherapy.

## Outlook

- Apply offline 3D gradient non-linearity correction.
- Calculate the mid-position volume.
- Develop an SMS-TSE sequence.

## Acknowledgements

MF Fast acknowledges funding by the Dutch Research Council (NWO) through project #17515 (BREATHE EASY).

## Contact information

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