5DMRI of Moving Organs

Zarko Celicanin[1] and Oliver Bieri[1]
[1]*Radiological Physics, University of Basel Hospital, Basel, Switzerland*

Target Audience: Scientists and clinicians interested in respiratory organ motion imaging and interventional MR treatment planning.

Purpose: Imaging of the organ dynamics is becoming increasingly important in numerous applications, such as in interventional MR and radiation therapy or for investigations on the physiological function of organs. An easy approach to image respiratory-resolved volumes of organs, commonly referred to as 4DMRI, are sequential 3D volume acquisitions. Repetitive volume scans are highly prone to intra- and interscan motion artifacts and, as a result, external respiratory surrogates [1], 1D pencil-beam navigator binning of volume acquisitions [2], or multislice 2D acquisition interleaved with a 2D navigator slice [3-5], were suggested to handle breathing-related organ motion.

Here, a novel 2D multislice 5DMRI, i.e. simultaneous respiratory- and cardiac-resolved, acquisition method is presented. It comprises self-gating retrospective sorting, thus requiring no navigators.

Methods: 5DMRI was developed from a prototype balanced steady state free precession (bSSFP) sequence. Multislice images were acquired continuously at the same slice position and in sagittal orientation to minimize out-of-plane motion [2] for a fixed number of repetitions with a TE/TR of 1.1/3 ms, image matrix 192×130, parallel imaging acceleration factor 2, FA 70º, bandwidth 1002 Hz/px, voxel size: 1.7×1.7×4 mm^3. The number of slices was adjusted to the size of the subject to enclose the whole liver with a large field-fo-view (FoV) to cover the lung and the heart. Temporal resolution was around 180 ms per image, resulting in a frame rate of 5.6 Hz. The acquisition was repeated 85 times at each slice location, which was around 15 seconds or around 5-7 breathing periods. Total scan time was around 15 min.

The principle of the retrospective sorting method is presented in Fig. 1. All images from the same position were analyzed by principle component analysis (PCA), to resolve the respiratory and cardiac signal as the second and third principle component, respectively [6]. These signals were then used to bin the acquired images in their corresponding respiratory and cardiac phases.

The feasibility of 5DMRI was investigated on a 1.5 T MRI system in a healthy subject after a written consent was obtained.

Results: Self-gating results are demonstrated for a slice position that included both the heart and the liver in the imaging plain (Fig. 2). Here, gating was especially challenging, since the deformation of the heart caused a strain on the liver from the top. Nevertheless, respiratory- and cardiac- gating with 5DMRI was successful to sort the images according to their respective respiratory or cardiac phases.

Two views of a 3D volume of reconstructed single respiratory and cardiac phase are shown on Fig. 3.

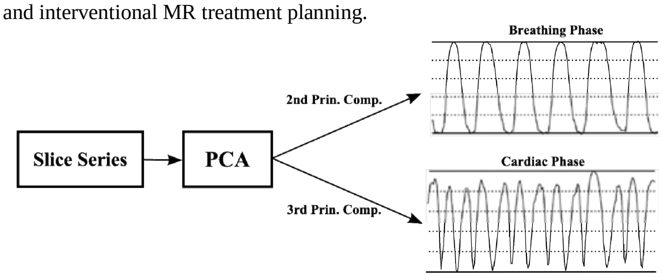

Fig. 1 *Retrospective sorting.*

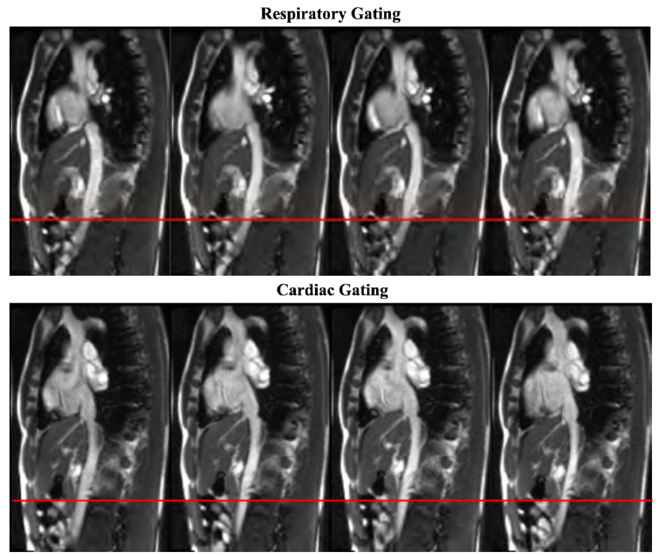

Fig. 2 *Respiratory and cardiac gating.*

Discussion: Slice-to-slice and bin-to-bin consistency of the proposed 5D MRI reconstruction method depends on motion reproducibility and the regularity of the breathing pattern. In principle, external respiratory surrogate signals, i.e. from a breathing belt or optical tracking, could be also acquired simultaneously with the other MRI acquisitions to improve the reconstruction. Alternatively, the use of an audio-visual feedback could regularize the breathing pattern and thus reduce the volume inconsistencies.

Here, rebinning was based on PCA to find correlations along the image time series, this approach should be more accurate than a simple binning based on a 1D pencil-beam navigator or external respiratory surrogates due to the liver deformations [3]. Moreover, 5DMRI, in contrast to 4DMRI additionally resolves the cardiac phase, influencing the shape of the blood vessels and surrounding tissues; potentially yielding more accurate organ motion models.

Since 5DMRI does not require to be interleaved by a navigator and does not require preparation pulses, it increases the temporal resolution and reduces the total scan duration significantly. Typically, imaging with bSSFP is performed with high flip angles at the limit of the specific absorption ratio (SAR), to increase vessel-tissue contrast from inflow effects. This, however, frequently causes subjects to feel uncomfortably warn [3]. In our approach, the overall reduced scan duration, mitigates this issue.

In contrast to previous methods, 5DMRI also resolves physiological motion from cardiac function and could thus prove beneficial in treatment planning and functional imaging.

Conclusion: Acquisition of pretreatment images for the purpose of estimating organ motion due to respiration and physiological, i.e. cardiac function, is an important step in the interventional MR and radiotherapy treatment planning. The acquisition of 5DMRI of moving organs was demonstrated to resolve respiratory and cardiac phase retrospectively. Further tests will be designed and investigated to evaluate the spatial accuracy and image contrast of tumors and other abnormalities.

References: [1] Tryggestad *et al.*, Med Phys 40:051909 (2013); [2] Tokuda *et al.*, Magn Reson Med 59:1051-1061 (2008); [3] von Siebenthal *et al.*, Phys Med Biol 52:1547-1564 (2007); [4] Remmert *et al.*, Phys Med Biol 52:N401-N415 (2007); [5] Cai *et al.*, Med Phys 38:6384-6394 (2011); [6] Odille *et al.*, Magn Reson Med 63:1247-1257 (2010).

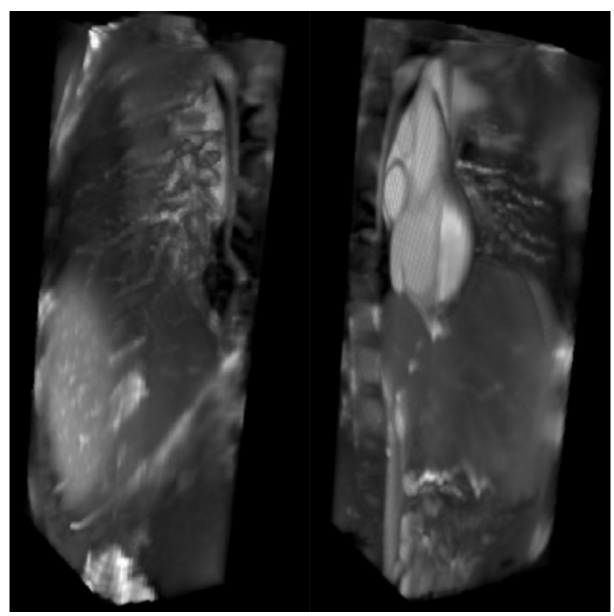

Fig. 3 *Two different views of a 3D stack.*