Extracting a cine cardiac cycle without respiratory motion from real-time free-breathing images with unsupervised motion correction

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TARGET AUDIENCE: Cardiovascular MRI, Radiologists, Cardiologists

PURPOSE: The current gold standard for assessing cardiac function with MR is breath-held, ECG gated, segmented cine imaging. While this method provides good temporal/spatial resolution, it does not perform well with patients who are unable to hold their breath. A viable alternative in such cases is free-breathing real-time imaging, which acquires each imaging frame in a single step. However, conventional real-time imaging methods suffer from poor temporal/spatial resolution. Additionally, real-time techniques generate a different number of phases per slice and per heart beat due to heart-rate variations during the scan. Even though it is possible to retrospectively generate a predefined number of frames per heartbeat from real-time acquisitions [1], respiratory motion complicates the analysis of such data sets. Kellman et al [2,3] previously showed that motion correction via image registration in conjunction with tissue tracking could be applied to real-time cardiac images to synthetically generate breath-held cine images. We propose a simpler, generalized approach without tissue tracking that generates single heartbeat, high SNR, breath-held cine images from any free-breathing real-time acquisition covering multiple heartbeats, including long axis views. Each cine phase is calculated by motion corrected averages from multiple heartbeats, typically acquired near end-expiration (or the most stable respiratory phase) during the respiratory cycle. The respiratory cycle trace is computed directly from the motion correction deformation fields without user intervention, and the technique can be used for imaging in any cardiac view.

METHODS: Segmented TrueFISP cine images and free-breathing real-time images were acquired in eight healthy volunteers (with IRB approval) using a clinical 1.5T MR scanner (MAGNETOM Aera, Siemens Healthcare, Erlangen, Germany): full short-axis stack (9-11 slices) and four chamber view. Segmented cine images were acquired with TR=38ms, 240x240 base matrix. TGRAPPA factor 4 was used during real-time data acquisitions with 6/8 partial Fourier; 128×128 base matrix, TR=43ms. The real-time cardiac images were acquired covering 20 beats per slice, and the data was processed using our prototype software as follows: (i) 25 cardiac phases per beat were generated for each slice using linear interpolation [1]. (ii) For each slice, interpolated images were averaged to obtain an initial reference image which corresponds to the most common organ positions for the particular subject, typically a diastolic cardiac phase at end expiration. (iii) Respiratory motion was estimated by first aligning all images from each cardiac phase with the corresponding reference image using 2D elastic image registration [3]. A pixel-wise sum of the deformation fields at each time point was calculated to obtain a 1D vector representing the net deformation or motion between each image and its corresponding reference. A low pass filter with cut-off frequency of 0.67 Hz (or 1.5 seconds, slower than an expected heart rate), was applied to this 1D time series to extract respiratory motion for each slice. (iv) Based on this respiratory motion, for each cardiac phase the images were ordered by their proximity to the reference (typically end expiration), and a new reference image was obtained by excluding 40% of images that are least similar to this reference, and averaging the remaining 60% heartbeat. (v) Images from the selected beats were registered to their respective reference image for each cardiac phase, and motion corrected images were averaged to obtain a high SNR single heartbeat at end-expiration. Both conventional segmented and motion corrected single heartbeat cine images reconstructed by the prototype software were analyzed to evaluate LV function (*syngo* Argus, Siemens Healthcare, Erlangen, Germany). A strip of pixels at the lung-diaphragm interface was plotted over time to validate the extracted respiratory trace.

RESULTS: The respiratory signal estimated from the deformation fields was in agreement with the conventional image based respiratory navigator (Fig. 1). Example end diastolic and end systolic short-axis images are presented in Fig. 2. Cardiac parameters calculated from the standard segmented cine images and motion corrected real-time images from our prototype software are presented in Fig 3. Values derived from the real-time images were in accordance with segmented cine results.

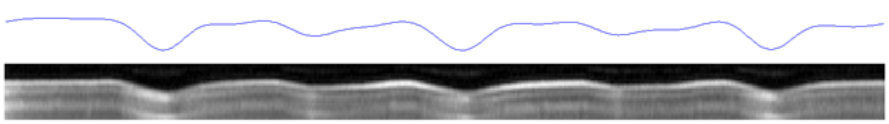

Fig 1. **Top:** respiratory cycle obtained from deformation fields (unsupervised). **Bottom:** conventional image based navigator obtained by plotting a strip of pixels at the lung-diaphragm interface as a function of time.

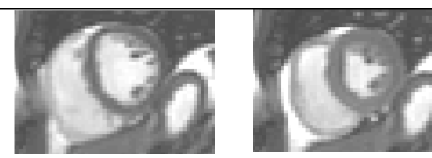

Fig 2. Motion corrected, breath-held, short axis end diastolic (left) and end systolic images (right)**.**

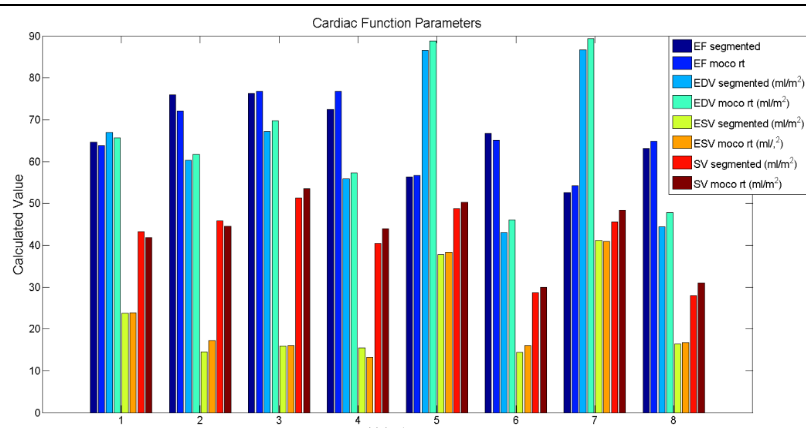

Fig 3. Comparison of cardiac function parameters from 8 healthy volunteers calculated by segmented cine and real-time (rt) free-breathing motion corrected (moco) images with the described post-processing. There is a good agreement in the following cardiac function parameters: ejection fraction (EF), end diastolic/systolic volumes (EDV/ESV), and stroke volume (SV). Average difference was 2%. Large differences were mainly due to the slight differences on the imaging planes between segmented and real-time acquisitions due to patient motion.

CONCLUSION: We have presented an unsupervised technique that generates single heartbeat, high SNR cine images at a particular respiratory phase from any multiple heartbeat, free-breathing real-time images. Cardiac functional parameters calculated using both prototype motion-corrected real-time and segmented breath-held cine images were in good agreement. The proposed method could also be adapted for 2D or 3D non-cardiac (e.g. abdominal) non-segmented data acquired over multiple repetitions.

REFERENCES: [1] Saybasili et al. #1844015**.** SCMR 2014. [2] Kellman et al.Magn Reson Med. 2008;59:771-8; 62:1557–1564. [3] Kellman et al. Magn Res Med. 2009; 62:1557–1564 [4] Guetter et al. ISBI 2011.