Non-rigid Motion-Corrected Averaging for Improved Pelvic MRI

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Introduction: Physiologic motion from bowel contraction and respiration can impact image quality in pelvic MRI. While respiratory motion can be addressed using respiratory gating or breath-hold acquisitions, the involuntary and aperiodic nature of bowel peristalsis makes prospective motion management less practical. Peristaltic contractions can be reduced by limiting food intake prior to imaging, or by administering antispasmodic agents such as glucagon or butylscopolamine. These approaches can be impractical and are not completely effective at eliminating physiologic motion in pelvic MRI (*1*). Without proper correction, this motion leads to blurring and limits the ability to perform high-resolution imaging in the pelvis.

In this work we propose the use of non-rigid motion-corrected averaging (MOCA) to retrospectively correct physiologic motion in pelvic imaging. The concept is to acquire a series of low signal-to-noise (SNR), fully-encoded images at a high sampling rate, estimate the non-rigid motion between each "frame" in the series, apply the motion correction to each frame, and then average the motion-corrected frames to recover the SNR and produce high-resolution, high-SNR images. This approach has been successfully demonstrated in managing respiratory motion in free-breathing MRI of the heart (*2*) and kidneys (*3,4*).

Purpose: To assess the feasibility of using MOCA to improve the image quality of pelvic MRI in the presence of bowel motion.

Methods: Two normal subjects participating in ongoing IRB-approved research protocols for ovarian and prostate cancer were scanned with modified T2-weigthed anatomical acquisitions to enable MOCA reconstructions. For the ovarian subject, scanned on a 3T Siemens TRIO scanner with body matrix and spine array coils, a 3D fast spin echo sequence (TR/TE=2000/100 ms, turbo factor 59, GRAPPA R=2, 130 x 130 x 48 mm FOV, resolution 0.5 x 0.5 x 1.5 mm, acquisition time 100 s) was acquired 4 consecutive times in 6.7 minutes, in place of our standard acquisition with 4 averages. For the prostate subject, scanned on a 7T Siemens Magnetom scanner with a 16-channel transceive surface array coil (*5*) a 2D multislice fast spin echo sequence (TR/TE=6000/72 ms, turbo factor 12, GRAPPA R=4, 220 x 220 mm FOV, resolution 0.7 x 0.7, 11 slices 2.0 mm thick, acquisition time 78 s) was acquired 8 consecutive times in 10.4 minutes. The MOCA reconstruction was performed in Matlab using the standard DICOM images produced by the scanner. The non-rigid registration was based on a modified Demons algorithm (*6-8*) and was derived from publicly available code from the University of Twente (*9*). The first frame of each series was used as a reference frame, and the subsequent frames were co-registered with the reference frame using an affine transformation followed by a Demons (2D or 3D) non-rigid transformation. The process was fully automated without the use of manual ROIs or landmarks. A normalized weighting factor was applied to each corrected frame based on the post-registration residual error to reduce the contribution of poorly registered frames (due to within-frame motion). After registration, the weighted, motion-corrected frames were averaged together to produce a single image set, which was subsequently compared with the equivalent non-motion corrected image set. Contrast-to-noise (CNR) was measured by dividing the range of signal intensities (max – min) in a selected ROI by the standard deviation of signal intensity in a noise region.

Results: Examples of 3D MOCA in the ovary (Fig. 1) and 2D MOCA in the prostate (Fig. 2) both show improved visualization of features in regions near bowel structures. In the ovarian case the visualization of the follicles is evident; in the prostate, the improvement in prostate anatomical detail is subtle (best viewed electronically), but improved visualization of the clinically-important prostate capsule can been readily seen. The CNR improved substantially in the prostate (25%) but only slightly in the ovary (1.8%).

Discussion: The two examples shown here demonstrate the feasibility of the MOCA approach for motion correction in the pelvis by using relatively few frames and long acquisitions (> 1min). The increased CNR observed in the prostate is attributed to reduced blurring of the small structures within the prostate. This effect is less notable in the ovary because the structures are larger and more uniform. The motion correction ability is limited: only motion *between* the frames can be corrected, while motion *within* each frame leads to blurring as in conventional averaging. The potential advantage of MOCA will be greatest when used with faster imaging (<10 s/frame) that can effectively "freeze" bowel motion. Further work will explore increased parallel imaging acceleration and compressed sensing approaches to shorten imaging acquisition time per frame. Note that if uniform weighting is used, there is no SNR or time penalty relative to conventionally reconstructed acquisitions that use signal averaging. If weighted averaging (as proposed here) or highly accelerated acquisitions are used there will be SNR costs. An optimization of frame rate, acceleration, and weighting strategies would enable tradeoffs between SNR and motion correction, and will be explored in future work.

Conclusion: MOCA can be used to reduce the effect of bowel motion in anatomical imaging of the pelvis, reducing blurring and improving contrast-to-noise. This may lead to higher resolution imaging and reduced need for antispasmodic drugs in diagnostic imaging.

References: 1) Froehlich JM, et al., Insights Imaging 2012; 2) Ledesma-Carbayo MJ, et al., JMRI 2007; 3) Positano V, et al., Magn Reson Mater Phy 2012; 4) Yang X, et al., Proc SPIE 2012 (doi: 10.1117/12.912190); 5) Snyder CJ, et al., MRM 2012; 6) Thiron JP, Med Imag Anal 1998; 7) Cachier P et al., Tech. Report, INRIA, RR-3706 1999; 8) Hong H, et al., Phys Med Biol 50(12) 2005; 9) Kroon DJ and Slump CH, IEEE Symp Biomed Imag (doi: 10.1109/ISBI.2009.5193214)

Acknowledgements: NIH P41 EB015894, R01 CA155268, S10 RR26783 and the WM KECK Foundation

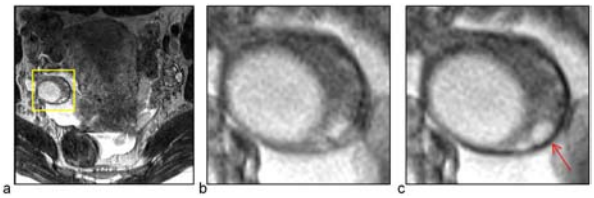

Figure 1 – Ovarian example at 3T. A full slice from a single frame of the 3D x 4 dataset (a) shows the right ovary with a dominant follicle, immediately adjacent to a contracting bowel loop. A zoomed view of the averaged (b) and 3D MOCA reconstructed image (c) shows improved visualization of the ovary and the follicles within (red arrow). The CNR over the ovary is similar with (28.6) and without (28.1) MOCA.

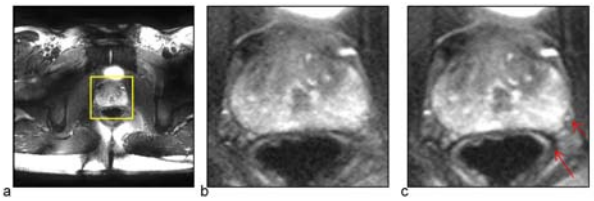

Figure 2 – Prostate example at 7T. A full slice from the 2D x 8 dataset is shown in (a), with zoomed images of the average (b) and the 2D MOCA reconstructed image (c). In this series there was moderate bowel contraction. While the improvement in feature visualization within the prostate is subtle, the rectal wall and prostate capsule (red arrows) are clearer, and the CNR over the prostate increased from 30.5 to 38.1 with MOCA.