MOtion Correction using Coil Arrays (MOCCA)

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Introduction: Robust motion correction is challenging in many MRI applications. Over the past two decades, several approaches have been proposed to suppress cardiac, respiratory or bulk motion [1-5]. We present a novel MOtion Correction method using Coil Arrays (MOCCA) that can be used for various motion corrections. In MOCCA, the elements of a coil array are used as individual motion "sensors" that detect the motion-induced signal variations modulated by individual coil sensitivity maps.

Theory: To apply MOCCA in a segmented k-space data acquisition, an additional non-phase-encoded k-space line (MOCCA line) is acquired before each imaging segment. Motion between the object and the stationary coils causes a variation in the *magnitude* of the MOCCA line signal. The amount and polarity of these variations are different between the coils depending on the geometric configuration of the coil array. To take advantage of these coil-dependent signal variations and to improve motion estimation accuracy, the MOCCA lines (magnitude only) from all the coils are stacked into a column vector (MOCCA echo). The MOCCA echoes, along with the coil sensitivities measured using a water phantom (individual coils divided by the sum-of-squares) and a low-resolution image (sum-of-squares of all coils) of the object estimated from the inner k-space segment, are included in the MOCCA algorithm (Figure 1). To estimate the motion, the low-resolution image undergoes a series of motion. After each motion, it is multiplied by each coil sensitivity map. The magnitude of k-space center lines for these shifted/rotated coil sensitivity-modulated low-resolution images was stacked into a column vector and the correlation coefficient (CC) between this column vector and the acquired MOCCA echo is calculated. The motion with the maximum CC is chosen as the estimated motion and a k-space linear phase is applied accordingly to correct the estimated motion. The motion estimation and correction steps are repeated for each imaging segment until full k-space is corrected for the motion.

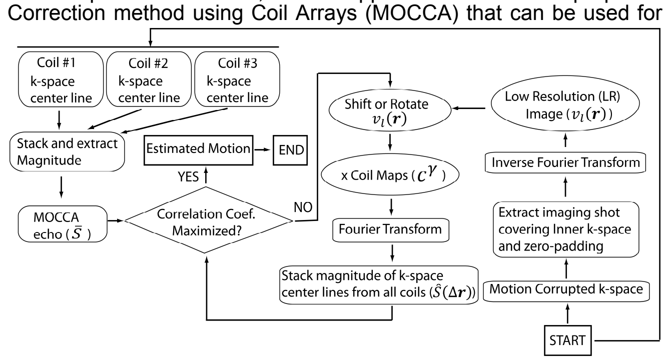

Figure 1: *Schematic of the MOCCA algorithm for translational and rotational motion correction*

Methods: Two examples of bulk motion and respiratory motion self-gating are presented to show the efficacy of MOCCA.

[Bulk Motion Correction]: A gradient echo sequence (TR/TE=3.7/1.8, α=15˚, resolution=2x2 mm^2, 8 segments) was used to acquire 8 full data sets of a phantom, each acquired after a manual translational motion (3-30mm) in both frequency-encoding and phase-encoding directions. MOCCA was employed to correct the motion in a motion-corrupted phantom data set synthesized from the 8 data sets. In addition, two other methods [1,2], projection center of mass (PROJ-COM) and projection CC (PROJ-CC), were applied with a single coil projection and with a combined projection using sum-of-squares from all the coils. The estimated motion in the projection direction was compared to the true motion measured from the scanner console. In vivo brain imaging was carried out using an SSFP sequence (TR/TE=4.4/2.2, α=80˚, resolution=1x1 mm^2). The subject was asked to move his head ~20mm (without rotation) in the phase-encoding (left-right) direction once between two imaging segments. MOCCA was applied on the motion-corrupted data.

[MOCCA respiratory self-gating]: Free-breathing ECG-gated free-breathing cine MRI was acquired on 4 healthy subjects each with four sequential averages. A MOCCA echo was acquired before each imaging segment for each cardiac phase. A MOCCA echo reference, which corresponds to the end-expiration, was calculated as follows: the average of the CC between the MOCCA echo in each heart beat and the MOCCA echoes acquired at the same cardiac phase in all remaining heart-beats was calculated. The MOCCA echo with the maximum calculated average was used as the MOCCA echo reference. Subsequently, for each imaging segment, the acquisition (out of four) with the largest CC value with the MOCCA echo reference was included in the final self-gated cine image. For comparison, conventional breath-held cine imaging was also performed. The quality of the images was graded by an experienced cardiologist using a four-point scale (1=poor,2=fair,3=good,4=very good) with data reported as the median [inter-quartile range]. The image scores were compared using the signed rank test with a Bonferroni correction for multiple comparisons.

Results: While the two projection-based methods were only able to correct for motion in the direction of projection, MOCCA was able to simultaneously correct for 2D motion using a single 1D MOCCA echo (Figure 2). Furthermore, the two projection-based methods underestimated motion in the direction of the projection if the projection is modulated by non-uniform coil sensitivity (standard error in motion estimates: MOCCA: 0.3mm, PROJ-COM: 1.8mm, PROJ-COM with single coil: 5.9mm, PROJ-CC: 0.5mm, PROJ-CC with single coil: 1.3mm). The head motion caused severe blurring and artifacts in the image (Figure 3). These were removed with MOCCA. In this example, the motion was mostly in the phase-encoding direction whereas the MOCCA echoes were acquired in the frequency-encoding direction. Therefore, the traditional projection-based methods would not be able to correct for the motion based on the same data. Figure 4 shows example cine images acquired during free-breathing without motion correction (a,d), with MOCCA self-gating (b,e), and during breath-holding (c,f). In all 4 subjects, MOCCA was able to remove respiratory motion-related artifacts. Compared to free-breathing cine MRI without motion correction, image quality was significantly higher with MOCCA self-gating (median difference in image score: 1.5 [0,2], p=0.023) and with breath-holding (median difference 2.0 [0, 2.5], p=0.047).

Discussions and Conclusions: We present MOCCA as a novel motion correction method for both bulk motion correction and self-gating in cardiac imaging. MOCCA is capable of accurately resolving arbitrary two-dimensional motion using a single 1D MOCCA echo. The inclusion of multiple coils by stacking multi-coil data into a MOCCA echo increases its accuracy of motion detection and correction. The concept of MOCCA can be readily integrated into existing motion correction methods to achieve improvements. Though presented for brain imaging and respiratory self-gating in cardiac cine MRI, MOCCA may be readily adapted to other anatomic regions in which motion correction is important.

References: 1. Lai et al., JMRI 2008;28:612-20. 2. Uribe et al., MRM 2007;57:606-13. 3. Larson et al., MRM 2004;51:93-102 4. Bammer et al., MRM 2007;57:90-102
5. Atkinson et al., MRM 2004;52:825-30

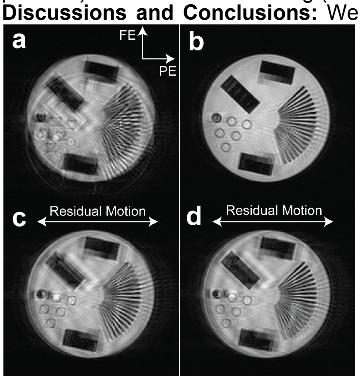

Figure 2: *a) Motion corrupted image, b) MOCCA corrected image, c) motion correction using PROJ-COM, d) motion correction using PROJ-CC. The methods using projections (c,d) are only able to correct for 1D motion whereas 2D motion can be corrected using a single 1D MOCCA echo.*

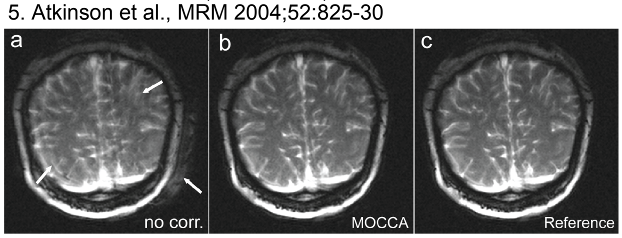

Figure 3: *A 2D brain image reconstructed from a motion-corrupted data set without motion correction (a), corrected with MOCCA (b) and a reference motion-free image (c).*

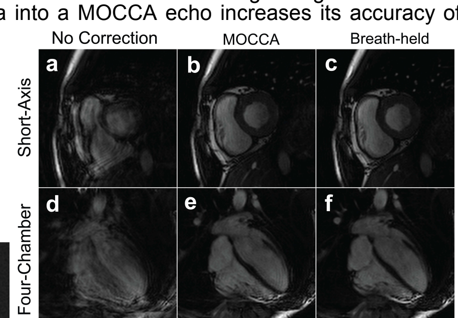

Figure 4: *MOCCA respiratory self-gating in double oblique cine MRI. (a,d) The free-breathing images without motion correction are corrupted by respiratory motion related artifacts and blurring. These are removed in the MOCCA cine images (b,e), which have similar image quality to the reference images (c,f) acquired using the standard clinical breath-held cine MRI.*