Highly Accelerated Single Breath-Hold Coronary MRA with Whole Heart Coverage Using a Cardiac Optimized 32-Element Coil Array

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Purpose

Clinical 3D coronary MRA (CMRA) is generally confined to multiple targeted thin slabs encompassing a particular segment of the coronary artery tree only due to the competing constraints of acquisition time, signal-to-noise ratio (SNR) and spatial resolution. Alternatively, the use of large imaging volumes, first made possible with free breathing techniques using mean acquisition times of approximately 13 min (1), supports the visualization of tortuous segments of the coronary arteries. Whole heart coverage breath-hold strategies have been elusive hitherto given practical constraints on the breath-hold duration, anatomic coverage and acquisition window length. For all of these reasons, a strategy employing many element RF coil arrays in conjunction with parallel imaging is conceptually appealing for the pursuit of comprehensive cardiac volumes in acceptable breath-hold times as recently demonstrated using mild accelerations and thick axial slabs (2). However, high baseline SNR is required to support the high accelerations required for such whole-heart breath-hold studies. To approach these challenges, the first aim of this study is to evaluate the performance of a new cardiac-optimised 32-element RF coil array for CMRA. Next we use this array in combination with highly parallel imaging to extend the achievable acceleration and volumetric coverage so as to achieve true whole-heart CMRA without exceeding clinically acceptable breath-hold times. Lastly the merits and limitations of the simplified whole heart coverage paradigm are discussed and its implications for clinical CMRA are considered.

Methods

An asymmetric cardiac-optimized 32-element two-dimensional array consisting of two clamshell formers, equipped with 21 anterior (∅=75 mm) and 11 posterior (∅=107 mm) elements, was designed. The posterior former was placed directly underneath the subject's torso while the anterior former was positioned on the subjects left chest (Fig. 1). A 32-channel acquisition system including multiple sets of system electronics (GE Healthcare Technologies, Waukesha, WI, USA) was employed for signal transmission and reception (3). A fat saturated, ECG gated 3D SSFP pulse sequence was customized to synchronize the prospectively ECG gated data acquisition for all 32 channels. 3D SSFP was performed using: FOV=41 cm, data matrix=256x256, TE=1.9 ms, TR=3.7 ms. Data acquisition was completed in a single heartbeat for each acquired slice partition. Unaccelerated phantom experiments were performed to compare baseline SNR between the cardiac optimized 32-element array and an 8-element cardiac coil (anterior/posterior 2 x 2 grid, element size 14 x 14 cm). The center of each coil was aligned with the S-I center position of the phantom (Fig 1). Accelerated whole-heart CMRA was then conducted on healthy adult volunteers, with simultaneous accelerations applied along both phase encoding directions. Net acceleration factors ranged from 8 (4x2, slice thickness=2 mm) to 16 (4x4, slice thickness=1mm). Large 3D axial slabs consisting of up to 120 slice partitions covering an S-I volume of 12 cm (interpolated voxel size of (0.8x0.8x1.0) mm^3) were acquired in a single breath-hold of 30 cardiac cycles. Images were reconstructed using the generalized encoding matrix (GEM) approach (4). For comparison the traditional targeted slab approach was applied in separate unaccelerated breath-hold scans to generate selective views of the right or the left coronary artery.

Fig.1: Coil positioning used (**top**) in phantom and (**bottom**) volunteer studies.

Results

For phantom studies using the 32-element cardiac array the approximate SNR obtained for a peripheral ROI placed 3cm below the anterior surface of the phantoms center (Fig 1) showed an SNR gain of approximately 350% as compared to the 8-element cardiac array. Although the 32-element array is comprised of elements that are considerably smaller than those of the 8-element array it provides depth penetration suitable for CMRA. The approximate SNR obtained for an ROI located in the center of the cylindrical insert (Fig 1) was 20% higher than that of the 8-element cardiac array. As shown in Fig. 2, use of the cardiac-optimized 32-element array did allow sufficiently high acceleration to achieve whole-heart coverage in a single breath-hold. Eight-fold accelerated parallel imaging in conjunction with 3D SSFP revealed good CMRA image quality (Fig. 3). The origin, proximal and more distal segments of the LAD and the RCA are clearly visible for the highly accelerated large volume approach (Fig 3, right). For comparison the image quality derived from the unaccelerated conventional restricted targeted slab approach is shown (Fig. 3, left). 3D views of the LAD and RCA obtained from an auto segmentation algorithm demonstrate the quality of the original individual images as well as the level of contrast achieved with the highly accelerated single breath-hold whole heart coverage acquisition (Fig. 4). For the imaging volumes and slice thickness used in this CMRA study the design of the 32-element cardiac optimized array can alleviate noise amplification to some extent for acceleration factors up to R=12 as demonstrated in Fig. 5, but electrodynamic constraints dictate that a fairly rapid degeneration of SNR at accelerations larger than R=12 may be inevitable.

Conclusions

The feasibility of single breath-hold whole heart coverage CMRA using a cardiac-optimised 32-element array has been demonstrated and the baseline SNR advantage over a conventional 8-element cardiac array has been shown. The highly accelerated whole heart coverage paradigm presented here promises to extend the capabilities of breath-hold CMRA from multiple targeted slabs to single large volumes. This supports the visualization of tortuous segments of the coronaries and reduces the demands for precise localization. Despite the clear SNR advantage of the cardiac optimized 32-element array, SNR remains a challenge as very large accelerations together with thinner than usual slice partitions for increased spatial resolution are explored. The use of higher magnetic field strengths would further improve the baseline SNR, and could potentially reduce the noise amplification in parallel imaging thereby helping to overcome some of these SNR constraints. The highly accelerated rapid volumetric approach illustrated here promises to be beneficial not only for CMRA but also for the assessment of other cardiovascular anatomy, cardiac function, myocardial perfusion and myocardial viability while improving both operator convenience and patient comfort.

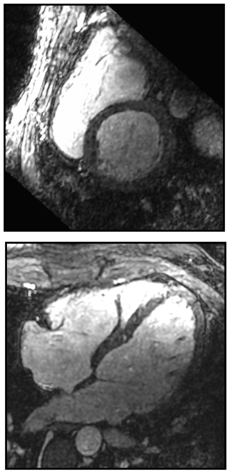

Fig. 2: Two chamber SAX (**top**) and four chamber LAX reformatted from a single breath-hold whole heart coverage data set (**bottom**).

Fig. 3: MR angiograms (reformatted MIPs,) of the LMCA and LAD (**top**) and the RCA (**bottom**) obtained with breath-held 3D SSFP using (**left**) the conventional thin targeted slab approach (matrix size: 256x256x12) and (**right**) 8-fold (4x2) accelerated parallel imaging using the whole heart coverage paradigm.

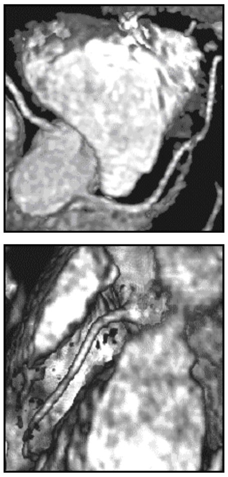

Fig. 4: 3D views of the LMCA/LAD (**top**) and RCA (**bottom**) obtained from auto segmentation using a ray-casting technique.

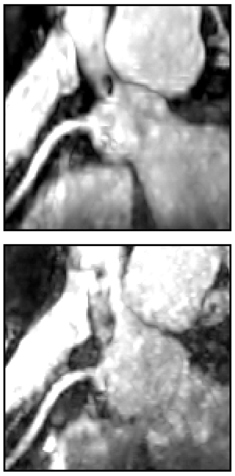

Fig. 5: Details of the RCA (MIP, see rectangle in Fig. 3.) acquired with net accelerations of (**top**) R=8 (2 mm slice thickness) and (**bottom**) R=12 (1.4 mm slice thickness).

References:
(1) Weber OM et al. Magn Reson Med. 50:1223 (2003), (2) Niendorf T et al, ISMRM, 703 (2004), (3) Zhu Y et al., Magn. Reson Med. 52,869 (2004), (4) Sodickson,DK et al, Med Phys 28, 1629 (2001)