Towards Whole Heart Coverage in a Single Breath-Hold: Coronary Artery Imaging Using a True 32-Channel Phased Array MRI System

T. Niendorf[1,2], D. K. Sodickson[2], C. J. Hardy[3], R. D. Darrow[3], R. O. Giaquinto[3], M. Saranathan[4], Y. Zhu[3], G. Kenwood[3], M. Harsh[5], T. K. Foo[4], N. M. Rofsky[2]

[1]Applied Science Laboratory, GE Medical Systems, Boston, Massachusetts, United States, [2]Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, United States, [3]GE Global Research Center, Niskayuna, New York, United States, [4]Applied Science Laboratory, GE Medical Systems, Baltimore, Maryland, United States, [5]GE Medical Systems, Waukesha, Wisconsin, United States

Purpose

Current 3 dimensional coronary artery MRA (CMRA) applications cover targeted slabs of limited thickness due to the competing constraints of acquisition time, signal-to-noise ratio and spatial resolution. Increasing the number of receiver channels in multi-coil imaging beyond the industry standard of 4-8 channels offers the potential for (**i**) signal-to-noise–ratio improvements (1) and (**ii**) scan time reductions due to the application of massively accelerated parallel imaging (2,3). This is of profound importance for addressing the problems of cardiac contraction and respiratory motion in diagnostic coronary artery imaging (CMRA). It also yields the potential to use large imaging volumes for whole heart coverage in a single breath-hold, which may render localizer scans obsolete and hence enhance patient comfort by substantially reducing examination times. This study demonstrates the technical feasibility of using a 32-channel coil array in conjunction with a 32-channel receiver system for short breath-hold thick slab coronary artery imaging. For this purpose conventional segmentation schemes and uni-/bi-dimensional parallel imaging strategies using up to 8-fold acceleration were incorporated into a 3D steady state free precession based imaging technique.

Methods

A 32-channel parallel array consisting of two clamshell formers, each equipped with 4x4 array of coil elements, was used (3,4). One former was placed underneath the subject's torso while the other was positioned on the subject's chest. For signal transmission/reception a 32-channel acquisition system including multiple sets of GE EXCITE system electronics (GE Medical Systems, Waukesha, WI, USA) was employed. The 3D FIESTA pulse sequence was customized in order to synchronize the ECG gated data acquisition from all 32 channels. Prospective ECG gating was achieved by using the physiological signal for the master cabinet and an external scope trigger for the slave cabinets. CMRA was conducted on normal volunteers. 3DFIESTA was performed using: FOV=32 cm, data matrix=256x192, TE=1.9 ms, TR = 3.7 ms resulting in an interpolated voxel size of (0.6x0.8x1.0) mm^3. For short breath-hold CMRA, 3D slabs consisting of up to 32 slices covering a volume of up to 6.4 cm were acquired. For parallel imaging, data acquisition is completed in a single heartbeat for each slice partition. An acceleration factor f of 2-4 was applied for uni-dimensional (k_y) acceleration, while an acceleration factor of up to 8 (4x2) was used for bi-dimensional decimation along the k_y and k_z dimension. For comparison the conventional VAST (5) acquisition scheme, which employs a 2 R-R interval segmentation for each slice partition, was applied. No contrast media were used. Images were reconstructed using the ASSET approach (6) for each cabinet or the generalized equation matrix approach (7).

Results

The application of 32 independent array elements, revealed superb image quality and SNR improvements for coronary artery imaging as demonstrated for the conventional approach (Fig. 1a) and the uni-dimensional parallel imaging strategy (Fig.1 c,d). The delineation of the distal portions is substantially improved for the 32-channel coil acquisition (Fig. 1a) vs. a standard 4-channel cardiac phased array coil (Fig. 1b). A longer segment of the diagonal branch is clearly visible when using the 32-element coil array (Fig. 1a). For the non-accelerated approach SNR was approximately 50 in the proximal and distal part of the RCA. The SNR increase obtained for the 32-channel coil was 40% compared to a standard 4-channel PA coil, and ~20 % compared to an 8-channel cardiac PA coil. Although the 32-channel coil is comprised of elements which are smaller than that of commercially available cardiac phased array coils, it provides depth penetration which is suitable for high SNR and robust coronary artery imaging as illustrated in Fig. 1c,d. Parallel imaging using an acceleration factor of 2 and 4 (Fig. 2a,b) eliminated the need for 2 R-R interval segmentation, used in the conventional approach, and hence enabled the acquisition of larger volumes without increasing the breath-hold time. The available SNR becomes increasingly challenging as the sensitivity encoding advances towards highly accelerated decimation (4x2) using the bi-dimensional approach. This is associated with the inherently broad coil sensitivity across the selected volume along the k_z-direction (A-P in this case) and hence makes it difficult to spatially distinct coil information.

Conclusions

The feasibility of rapid breath-hold coronary artery imaging using 32 independent coil elements, which is beyond that generally used in clinical applications has been demonstrated. The initial experience suggests that breath-hold CMRA with a 32-channel system may provide benefits for clinical cardiac MR. The use of a thick slab volume, together with factor 2-8 accelerated parallel imaging demonstrated here, promises to extend the capabilities of breath-hold CMRA from multiple targeted slabs to the acquisition of single large volumes in concert with retrospective isolation of the coronaries. This supports the visualization of tortuous segments of the coronary arteries and reduces the demands for precise localization. It offers the potential to even skip the localization entirely by applying large, straight axial volumes, which cover an appropriate segment of the heart including the major branches of coronary arteries instead of positioning multiple targeted slabs in a more time consuming setup. Higher accelerations, at the level of an order-of-magnitude, would not only extend the benefits of acceleration for the reduction of motion sensitivity but they would also allow single breath-hold whole heart coverage using a 10-12 cm volume. Large imaging volumes also help to render sensitivity encoding along the 3rd dimension suitable for CMRA because of an improvement in the coil sensitivity difference, which results in a reduction in the noise amplification. In conclusion, robust single breath-hold CMRA promises further scan time reduction compared to free-breathing techniques. This offers the potential to integrate CMRA into a comprehensive cardiac examination for the detection of heart disease without sacrificing patient comfort.

a)   b)   c)   d)
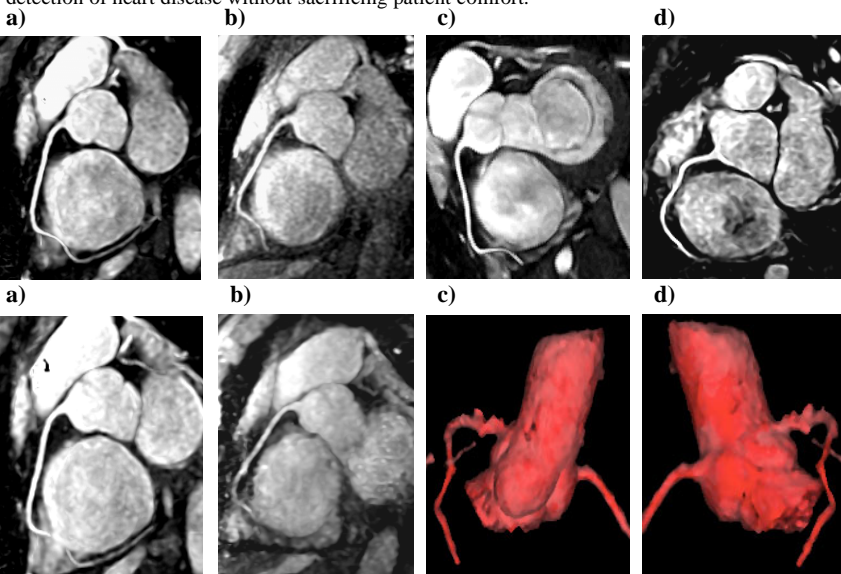
Fig. 1: Comparison of breath-held 3DFIESTA images, of the right coronary artery (maximum intensity projection, slice thickness=3 mm) obtained from the same volunteer using (**a**) a 32 channel and (**b**) a standard 4-channel phased array coil. The distal portion of the RCA is clearly visualized in the 32-channel coil image due to a 40 % SNR improvement over the 4-channel coil image. The overall image quality obtained with the 32 channel coil using twofold uni-dimensional acceleration incorporated in ECG-gated 3D FIESTA is illustrated in **c**) and **d**). All images were acquired in a 25sec breath-hold.

a)   b)   c)   d)

Fig. 2: RCA images (MIP) derived from a healthy volunteer using uni-dimensional acceleration (**a**) f=2, and (**b**) f=4. The breath-hold time was 12 sec. Note the clear delineation of the origin and the proximal segment. 3D volume rendered views derived from a single breath-hold 3D FIESTA (acceleration factor f=2) data set consisting of 32 straight axial slices, which cover a large volume of 6.4 cm is shown in **c**, **d**. The origin and the proximal segments of the RCA and LCA are very well depicted.. No extra time consuming localization scans were applied for the slab positioning, except a 1 sec. sagittal scout scan .

References: (1) Roemer P.B. et al. MRM 16, 192 (1990), (2) Sodickson D.K. et al., MRM 38, 591 (1997), (3) Zhu Y. et al., ISMRM Proceedings, 22 (2003), (4) Hardy, C.J. et al., ISMRM Proceedings, 471 (2003), (5) Foo. T. et al. , ISMRM Proceedings, 1642 (2002),), (6) King K.F. et al., ISMRM,153 (2000, (7) Sodickson, D.K., Med Phys 28, 1629-1643 (2001)