32-Element Coil Array for Highly Accelerated Clinical Cardiac MR Imaging

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Purpose

In current clinical practice, cardiac MRI (CMR) is generally confined by the competing constraints of breath-hold duration, anatomic coverage, spatial resolution and viable acquisition window to multiple slices or targeted thin slabs encompassing a particular section of the heart. Parallel imaging can overcome these difficulties by allowing volumetric acquisitions (1-3), but many-element coil arrays configured for CMR need to meet the practical demands for patient comfort and ease of clinical use (1,4,5). For all of these reasons, the main aim of this study is to compare a newly designed, light weight 32-element cardiac array with a standard 5-element cardiac coil at 1.5 T. For this purpose, the signal-to-noise ratio (SNR) and geometry factor (g-factor) performance of the new 32-element cardiac array is examined. Its clinical efficacy for highly accelerated whole heart coverage imaging is demonstrated in rapid left ventricular (LV) function assessment and coronary artery imaging (CAI).

Methods

The 5-element cardiac array (Philips, Best, Netherlands) consists of 2 circular, anterior elements (∅=20 cm) and 3 posterior rectangular loops (20x14 cm^2) (Fig 1a). The new 32-element cardiac array (Philips Research-Europe, Hamburg, Germany) consists of 16 anterior and 16 posterior hexagonal elements (∅=12 cm) arranged in a 4 x 4 matrix (Fig 1 a). The anterior coil is highly flexible and bends around the left side of the chest leaving a cutout for the left arm. The posterior coil is integrated in a lightweight foam former (l=120 cm), which eliminates the need for extra cushions in a clinical setting (Fig. 1c). All experiments were performed on a 32-channel 1.5 T MR system (Achieva, Philips, Best, Netherlands). Phantom experiments were carried out to compare the baseline SNR of the 32-element with the 5-element cardiac array. For this purpose, a loading phantom (50 x 35 x 27 cm^3) was designed to simulate an average subject. Both coils were positioned according to the *in vivo* situation (Fig 1b). Noise was derived pixel-by-pixel from the standard deviation of the signal intensity time course over 50 dynamic scans. Maps were made of the ratio of SNR achieved with the 32 element coil to that achieved with the 5-element coil (SNR_{ratio}). G-factor maps were derived from 1D and 2D accelerated 3D gradient echo images. Mean and maximum g-factors were determined for a 22 cm slab placed around the F-H center of the phantom. Highly accelerated whole-heart CMR was conducted on healthy adult subjects. A 3D CINE SSFP technique was used for single breath-hold LV assessment (20 slices, matrix=272x272, FOV=38 cm, 20 cardiac phases) together with net accelerations ranging from R=6 (R_y=3, R_z=2) to R=10 (R_y=4, R_z=2.5). For comparison, 1D accelerated 2D CINE imaging using R_y=1-4 placed along the L-R direction was performed (matrix=272x272, FOV=38 cm, 25 cardiac phases). Highly accelerated whole heart coverage CAI was conducted with free breathing or single breath-hold acquisitions using a fat saturated, 3D SSFP technique and net accelerations of up to R=8.75 (R_y=3.5, R_z=2.5).

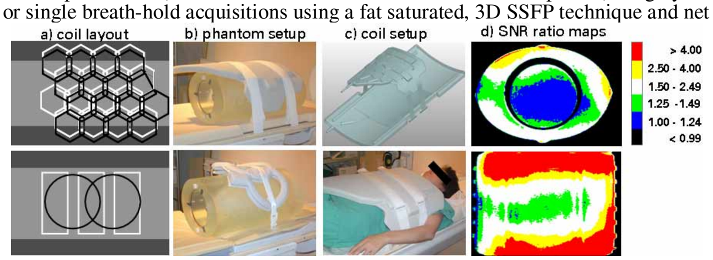

Fig.1: a) Layout of the 32- **(top)** and 5-element **(bottom)** coil (anterior section: black, posterior section: white). The central gray area marks the region included in the SNR and g-factor quantification. **b)** Coil positioning used in phantom experiments. **c)** Light-weight foam formers **(top)** and coil position for clinical studies **(bottom)**. **d)** SNR ratio maps derived from **(top)** a series of axial (F-H coverage=22 cm) and **(bottom)** a stack of coronal slices (A-P coverage=27 cm) illustrating the SNR advantage of the 32-element over the 5-element array.

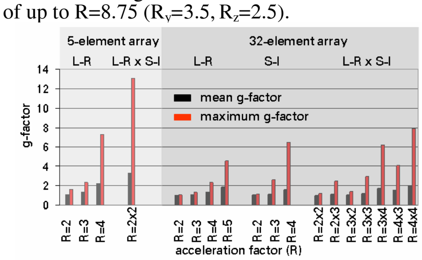

Fig. 2: Mean and maximum g-factor obtained for 1D and 2D accelerations along the L-R and F-H direction of the 5-element and 32-element coil array. The 3D data acquisition (TE=3.0 ms, TR=7.0 ms) covered a volume of $(40x40x22\ cm)^3$.

Results

For phantom studies the 32-element array showed a baseline SNR gain over the 5-element cardiac coil ranging from SNR_{ratio}=1.5 to SNR_{ratio}=2.49 for peripheral regions. Regions close to the coil elements revealed an SNR gain larger than 2.5. The 32-element array provides depth penetration suitable for CMR - the SNR gain obtained for the central region, mimicking the hearts position in the chest cavity, was found to be between SNR_{ratio}=1.00-1.49 as indicated by the blue and green colours in Fig 1d. The 32-element array's g-factor performance was found to be superior to the standard 5-element array for both 1D and 2D accelerations (Fig. 2). Short axis views demonstrate the image quality as well as the level of contrast achieved with conventional and up to 4-fold accelerated 2D CINE SSFP (Fig. 3a). As shown in Fig. 3b, use of the 32-element cardiac array did allow sufficiently high acceleration to achieve whole-heart 3D CINE in a single breath-hold. An acquired in-plane resolution of (1.4 x 1.4) mm^2, which is equivalent to that generally used in traditional 2D acquisitions, was achieved while preserving a temporal resolution of 20 acquired cardiac phases. Seven-fold accelerated single breath-hold whole heart coverage 3D SSFP enabled 1.5 mm (acquisition size) isotropic in-plane spatial resolution (82 reconstructed slices each 2 mm thick) and produced images suitable for rapid screening of coronary anatomy (Fig. 4a). 7-fold accelerated free breathing whole heart coverage CAI (160 slices) using 3D SSFP facilitated an acquired spatial resolution of (1.0x1.0x1.5) mm^3 and served to reduce a 6:30 min conventional scan time to 53 sec (Fig. 4b). The origin, proximal and more distal segments of the LAD, RCA and LCX are clearly visible for highly accelerated free breathing and breath-hold CAI (Fig 4a,b).

Conclusions

The 32-element cardiac array was found to meet the various demands of highly accelerated clinical CMR. It provides excellent patient comfort and ease of use due to its light weight and flexibility. The new 32-element coil exhibits a significant SNR and g-factor advantage over the 5-element cardiac array. Overall, the array´s performance enabled highly accelerated whole heart coverage LV assessment and CAI. The accelerated paradigm can simplify and streamline clinical CMR by replacing multiple slice acquisitions or targeted scans with a single accelerated volumetric acquisition, while preserving the spatial resolution of the traditional approach. The volumetric approach also supports retrospective visualization of standard cardiac views or tortuous segments of large vessels and coronary arteries by avoiding the frequently-encountered difficulty of missed target territory.

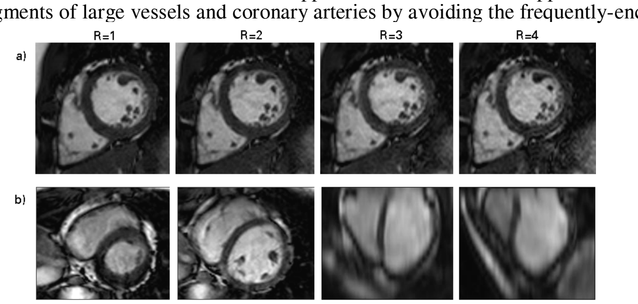

Fig. 3: Images acquired with the 32-element coil **a)** Two chamber short axis view obtained from 2D CINE imaging using 1D accelerations of up to R=4. **b)** Two chamber long axis view derived from 16 sec breath-hold 3D CINE (R_x=4, R_y=2) **(left:** systole, **middle left:** diastole). Four **(middle right)** and three chamber **(right)** long axis view obtained from retrospective reformatting of a whole heart coverage data set.

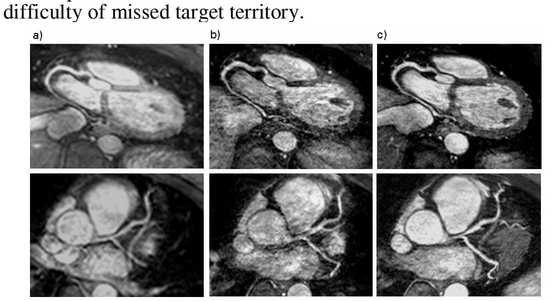

Fig. 4: MR angiograms (curved MIPs) of the RCA, LMCA, LCX and LAD, obtained from whole heart coverage imaging using 7-fold accelerated **a)** single breath-hold and **b)** free breathing 3D SSFP. For comparison, the MR angiograms obtained from the unaccelerated free breathing scan are shown in **c)**. Images were acquired with the 32-element coil array.

References: 1) Sodickson D.K. et. al. Acad. Rad. 12:626,2005 **2)** Niendorf T. et al. Magn Reson Med. 56:167, 2006 **3)** Nehrke K. et al. JMRI 23:752, 2006 **4)** Hardy C.J. et.al. Magn Reson Med. 55:1142, 2006 **5)** Lanz T. et. al. ISMRM 2006 2578