Faster Free-Breathing 3D Coronary MR Angiography using Multi-Stack Spiral Imaging

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Introduction

Three-dimensional spiral imaging, a scheme that samples data in k-space very efficiently, seems to be very useful in cardiac applications. Thedens et al. (1) showed successfully the feasibility of spiral 3D coronary MRA. However, despite methodological advances, such as e.g. thin slab double-oblique 3D acquisition, spiral scanning times for free breathing protocols are still rather long. To reduce the total measuring times of 3D spiral imaging, ref. (2) showed that the sampling efficiency can be increased by a factor of 2-3 if several spiral interleaves are sampled within each heart beat (R-R) interval. However, a further scan time reduction for an entire coronary protocol seems to be possible by acquiring the different thin 3D double-oblique slabs almost simultaneously (in different cardiac phases) each covering a selected branch of the coronary artery tree (RCA, LAD, RCX). This was theoretically suggested by Thedens et al. (3) and shown experimentally successfully by Manke et al. (..) recently for a Cartesian gradient echo protocol.

It is the aim of this paper to show that fast free breathing, sub-millimeter 3D spiral imaging can further be accelerated due to the simultaneous acquisition of multiple 3D stacks.

Methods

Healthy volunteers (informational consent obtained) were studied using a commercial 1.5 T whole body scanner (Gyroscan, ACS-NT15, Philips Medical Systems) and a three-element synergy coil.

The coronary MRA protocol to be discussed enables the simultaneous acquisition of multiple geometrically independent 3D stacks (within the R-R interval), each covering a different portion of the coronary artery tree and each is oriented along the individual vessel axis (c.f. Fig. 1). Restricting us to two individual stacks the corresponding trigger delays of the two cardiac acquisition windows can be chosen independently in the cardiac cycle. Each imaging block can be preceded by an individual tailored magnetization preparation phase (T2 preparation, fat saturation, regional signal suppression etc., c.f. ref (4)) and a respiratory navigator used for gating and prospective motion correction. To show the basic feasibility in the present experiments only one magnetisation preparation step (T2 preparation and chest wall signal suppression) was performed after an appropriate R-wave trigger delay prior to the acquisition of both geometrically independent stacks covering the RCA and the LAD. Data acquisition was performed in late diastole.

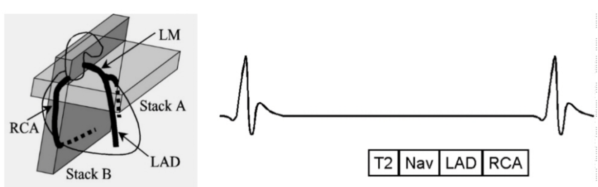

Fig.1 Arrangement of two independent stacks covering the RCA and LAD measured subsequently after magnetization preparation.

The data of the individual stacks were acquired using the stack of spiral approach (5) where conventional phase encoding is performed in the third dimension. The corresponding 2D sub-k-space was traversed with variable angular speed spiral using 42 interleaves, each with a sampling window of 20 ms (TE: 5 ms, TR: 33 ms, 512 x 512 x 10 scan matrix, voxel size: 0.7 x 0.7 x 3 mm³). The high TE is a consequence spectral spatial excitation pulse (6) which is used for each spiral interleave to excite only the water and to suppress the epicardial fat signal. To speed up data acquisition two spiral interleaves were sampled subsequently for each stack. To maintain the same signal in these consecutive interleaves a flip angle sweep (45°, 90°) was applied. The resulting cardiac acquisition window for one stack is about 66 ms. Image reconstruction was performed by gridding and Fourier transform. All single coil spiral images were additionally corrected for spatial off-resonance blurring using a conjugate phase reconstruction (7) based on a measured field map. Image combination was performed using the sum of square approach.

Results

High-resolution 3D spiral images were obtained in all measured individuals. The major parts of the proximal coronaries (RCA, LAD) could be visualized with a good contrast between the arterial blood pool and the surrounding tissue. In Fig. 2, two reformatted images of a double stack acquisition are shown. The scan time for this particular spiral approach is equivalent to 210 accepted heartbeats. In the volunteers we have studied the total scan time ranged between 6 - 8 minutes. Assuming a cardiac rate of 60 bpm and a navigator gating efficiency of 50 % the total scan time is around 7 minutes.

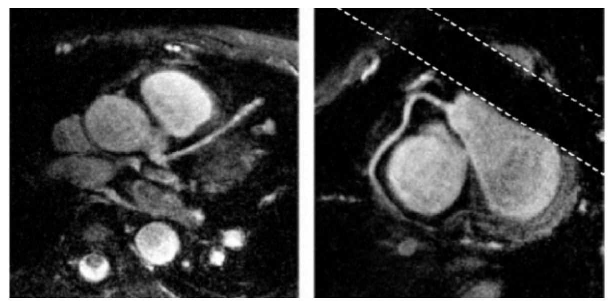

Fig.2 Example of a spiral double sack acquisition (LAD, RCA). In the RCA image the saturation trace of the LAD stack is indicated.

Discussion

The basic feasibility of multi-stack 3D spiral imaging was shown in the present study. The problem in multi-stack imaging is the overlap region of the two imaging volumes (3) As can be seen in Fig. 2 this gives rise to a saturation effect, which is only visible in the second imaging volume and is less critical for the right coronary artery (RCA) than for the left anterior descending artery (LAD) for geometrical reasons. Therefore in all examinations the LAD was imaged in the first and the RCA in the second selected cardiac phase. In most cases the RCA was not affected by the saturation stripe, since it was located inferior to this region. Coverage between the LAD and RCA imaging volume near the proximal portion of the RCA can be avoided by a conscientious planning of the imaging volumes.

Thus, by tilting and adjusting the LAD stack to the individual anatomy of the subject the saturation problem loses its tension. The use of blood pool contrast agents, which could solve this problem due to the increased T1 relaxation is questionable for spiral applications because their use is accompanied by T2* effects which could restrict the spiral data acquisition window.

Free breathing, multi-stack, fast 3D spiral coronary MRA covering the major branches of the coronary artery tree shows the potential for visualization of all proximal coronary arteries (RCA,LAD, RCX) in about 7 min. This could be the basis to integrate coronary artery imaging into the concept of the MR 'one-stop-shop'.

References

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