Dual breath-hold 3D whole heart cine cardiac MRI: feasibility and initial experience

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Introduction Two-dimensional (2D) multiphasic cine balanced steady state free precession (bSSFP) MRI is the reference method to assess cardiac function [1]. Typically, separate acquisitions along each of the major cardiac axes are made during suspension of breathing with high in-plane spatial resolution (1-2 mm) as well as high temporal resolution (up to 50 frames per cycle). Depending on the desired anatomical coverage, each of these acquisitions is usually gathered over multiple patient breath-holds. After the acquisitition has been completed cardiac chamber volumes and ejection fractions are calculated by segmenting short-axis slices with the sum-of-slices method (SoS). This 2D method requires manual positioning of short-axis planes prior to the acquisition (i.e. during the MR acquisition), and is therefore time-consuming and labor intensive. A full cardiac balanced SSFP cine exam, including planning of the acquisitions, can thus easily take 15 min [2]. These long acquisition times have prompted the search for techniques to significantly increase imaging speed in order to minimize acquisition time and the number of breath-holds needed. Whereas prior work has focused on decreasing imaging time for individual cardiac orientations (e.g. single breath-hold short axis coverage [3,4]), or time-consuming whole heart respiratory navigator-gated methods [5], we propose a dual breath-hold 3D isotropic cine bSSFP acquisition with whole heart coverage that permits *a posteriori* selection of any desired imaging plane. Here we demonstrate the feasibility of this method and compare it with standard multislice 2D cine imaging for determination of LV function.

Methods All MR imaging was performed on a clinical 1.5T scanner (Ingenia (R4.2), Philips Healthcare, Best, the Netherlands), equipped with a 28-element torso phased-array surface body coil. Prior to cine imaging interactive scout views were obtained of the chest and heart followed by retrospectively gated 2D bSSFP cardiac cine imaging (TE = 1.7ms, TR = 3.4ms, flip angle = 60º, matrix = 192x183, pixel spacing of 1.25x1.25, slice thickness 8mm) at 30 cardiac phases in the right and left vertical long axes (VLAx), horizontal long axis (HLAx), short axis (ShAx) and left ventricular outflow tract (LVOT). Only short-axis slices were used for semi-automatic volume quantification by the sum-of-slice method (Cardiac explorer, Philips EWS, Philips Medical Systems). Whole heart isotropic cine datasets were acquired in two breath-holds with a 3D isotropic bSSFP sequence acquired in the transverse plane (TE = 1.4ms, TR = 2.8ms, flip angle = 50º, matrix = 144x144x25, voxel spacing of 2.43x2.43x2.5mm) using parallel imaging sensitivity encoding (SENSE) with acceleration factors of 2.5 in anteroposterior direction and 2 in the caudocranial direction. Data from individual breath holds were fused in 4 dimensions after acquisition to generate a single isotropic (retrospectively gated) 30-cardiac phase imaging volume covering the entire heart, using zero-padding in the slice direction (overcontiguous slices). For comparison with the conventional multislice 2D bSSFP method, 8 mm thick short-axis slices were retrospectively reconstructed with dedicated post-processing software by manually indicating the center of the mitral valve (MV) and the cardiac apex in orthogonal slices of the transverse data. Subsequently, short-axis slices were reconstructed perpendicular to the MV-apex line, in which endocardial contours were manually drawn. The reconstructions generated from the 3D acquisitions were analyzed by two observers in consensus, blinded for the results of 2D bSFFP cine imaging. End-diastolic and end-systolic volumes (EDV and ESV) were computed and ejection fraction (EF) was derived. Quantitative results were compared for the two methods.

Results 3D whole heart datasets were successfully acquired in three consecutive patients with anatomically corrected transposition of the great arteries (ages [19-41 y]). There were only minimal modulations of signal intensity and stairstep artefacts. In each patient a set of ShAx slices could be reconstructed for quantitative analysis of LV function. Acquired and reconstructed frames in the left and right VLAx, HLAx and ShAx orientations are shown in figure 1, EDV, ESV and EF measurements in figure 2 and 3. Mean absolute EDV and ESV errors were 8.0 and 4.3 mL, respectively. The mean absolute EF error was 1.7%. These results demonstrate the feasibility of accurate quantitative LV functional assessment from dual breath hold multiphase 3D bSSFP whole heart imaging with similar accuracy as the reference standard.

Discussion The results of this study demonstrate the feasibility of a fast, 3D whole heart cine bSSFP acquisition in two breath-holds. Initial experience indicates good agreement with the reference method for quantitative assessment of LV function and a substantial timesaving over the respiratory navigator-gated approach described by Uribe et al [5]. The proposed 3D method can reduce acquisition time of cine imaging to less than 1 min, and limit the number of breath-holds for patients. Furthermore, examination time can be shortened because *a priori* identification of the major cardiac imaging planes is no longer necessary, as these views can be retrospectively reconstructed from the acquired data. The truly 3D cine, isotropic acquisitions were downsampled for fair comparison with the reference method, but quantification can be enhanced by analysis on thinner short-axis slices, exploiting the full resolution of the data and reducing variability due to approximation of the most basal slice. The dense data might also be beneficial for automated post-processing techniques. In this study, data from two consecutive breath-holds was fused. Although such fusion may cause stitching artifacts due to inconsistent breath-holds, with associated quantification errors, these were minimally present in our data.

Conclusions Whole heart dual breath-hold 3D cine bSSFP cardiac MR with retrospective reconstruction of any desired viewing plane is feasible and allows fast and accurate assessment of global LV functional parameters. This method may be of value in subjects that are unable to undergo a complete cardiac evaluation with conventional 2D cine bSSFP methods.

[1] Moon et al. *Radiology* 223 (2002) 789-797
[2] Heilmaier et al. *Eur J Rad* 74 (2002) 492-499
[3] Wintersperger et al. *Eur Radiol* 17 (2007) 73-80
[4] Eberle et al. *Eur Radiol* 20 (2010) 73-80
[5] Uribe et al. *Magn Reson Med* 57 (2007) 606-613

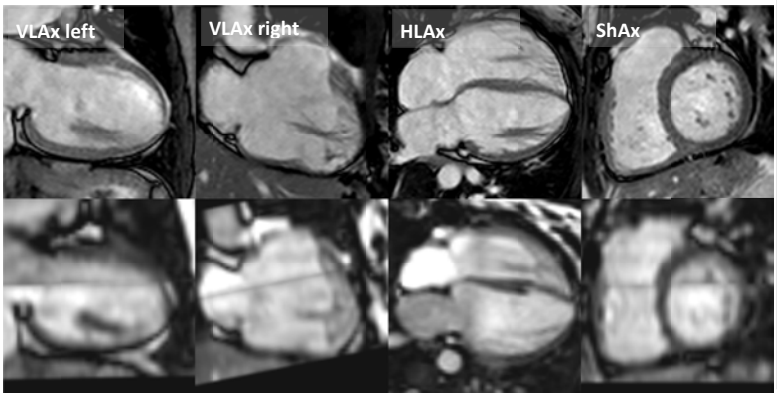

Fig. 1. ***Top***:*End-diastolic 2D left and right VLAx, HLAx and ShAx images.* ***Bottom***: *Corresponding reconstructions from the 3D acquisition.*

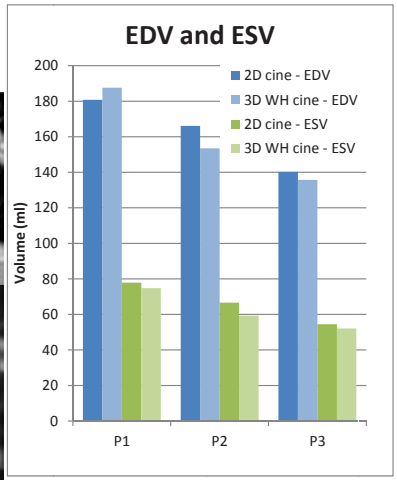

Fig. 2. *Volumetric measurements using 2D cine and 3D whole heart (WH) cine.*

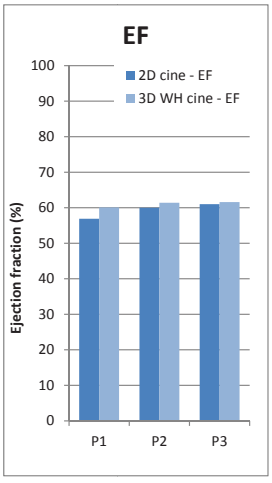

Fig. 3. *Ejection fraction by the two methods.*