Free breathing black-blood systolic imaging using heart rate prediction and motion compensated reconstruction

M. Lohezic[1,2], B. Fernandez[1,2], J. Oster[2,3], D. Mandry[2,4], O. Pietquin[3,5], P-A. Vuissoz[2,3], and J. Felblinger[2,3]
[1]Global Applied Science Lab., GE Healthcare, Nancy, France, [2]IADI, Nancy-Université, Nancy, France, [3]U947, INSERM, Nancy, France, [4]CHU de Nancy, Nancy, France, [5]IMS Research Group, SUPELEC-Metz Campus, Metz, France

INTRODUCTION: Double Inversion Recovery Fast Spin Echo (DIR-FSE) sequences, resulting in black-blood images, are widespread in cardiac exams [1] as high resolution and great contrast between heart cavities and walls are achieved. For these sequences, DIR pulses are generally played on the R wave and the inversion time (TI) needed to cancel blood signal (~500ms) only allows diastolic view of the heart. Cardiac contraction is complete at end systole so myocardium can be better observed during this short phase. To perform systolic acquisitions, DIR pulses have to be placed before the R wave in the previous heart cycle and RR interval prediction is mandatory. Moreover, as systole is generally shorter than diastole, shorter echo trains are desirable, resulting in longer acquisition time incompatible with breath hold. A method which combines (i) heart rate prediction [2], (ii) respiratory motion estimation [3] and (iii)motion compensated reconstruction [4] is presented. It allows free breathing black-blood systolic imaging and has been tested on five subjects.

MATERIAL & METHODS: Five healthy volunteers underwent cardiac examination at 1.5T (SIGNA HDx, GE Healthcare, Milwaukee, WI). For each subject, four images were acquired with black blood FSE sequences, one during breath hold and three while free breathing, using the same parameters (TE=20-35ms, TI=500ms, matrix size: 256x256, FOV=36cm, BW=125-250kHz, slice thickness=6mm) except Echo Train Length (ETL) which was set at 16 for breath hold acquisitions (20s) and 8 in free breathing (40s). Signals from two respiratory belts and ECG sensors were carried by a custom Maglife patient monitoring system (Schiller Medical, France) and recorded with a dedicated home-made hardware presented in [3]. RR interval prediction, described in [2] on breath-hold data, was adapted for free-breathing acquisitions. It was performed using Kalman filtering with respiratory signals and previous RR intervals as inputs. An external trigger signal, which took into account the needed TI and the desired Trigger Delay (TD=300ms), was then used to launch the sequence including DIR preparation (*Fig. 1*). To deal with free breathing acquisitions, a respiratory motion model has been introduced [3]. Displacement fields *u(r,t)* are estimated at each echo train *t* using physiological signals $S_k(t)$:

$$u(r,t)=\sum_{k=1}^{K} S_k(t)\alpha_k(r) \quad (1)$$

, where α_k are learned motion coefficients.

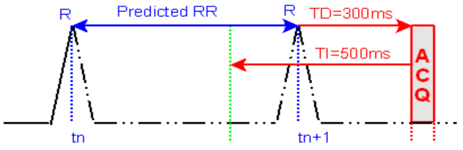

Fig. 1 : Heart rate prediction and sequence timing

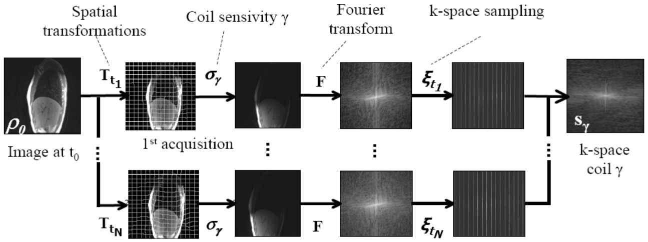

Fig. 2 : Encoding operator used for generalized reconstruction

To reconstruct image ρ from free breathing data *s*, GRICS algorithm [4] has been used. It consists in the inversion of two coupled systems:

$$\begin{cases} s = E(\alpha)\rho \\ \varepsilon = s - E(\alpha)\hat{\rho} = R(\rho,\alpha)\delta\alpha \end{cases} \quad (2).$$

The first system is a motion compensated reconstruction consisting in finding the pseudo-inverse of the generalized encoding operator $E(\alpha)$ which includes spatial transformations obtained from *(1)* (*Fig. 2*). The second system leads to the update $\delta\alpha$ of the motion model coefficients α. A multi-resolution fixed-point method is proposed for solving systems *(2)*, the motion model being initialized with zero coefficients. As in previous work [4], four respiratory inputs (two respiratory belts and their derivatives) were used. In addition, exact cardiac phase positions of echo trains are also considered as a physiological input to compensate residual cardiac motion due to RR prediction jitter.

RESULTS: Image quality has been assessed through 2 criteria: image entropy, which increases with artifacts and noise, and gradient entropy, which decreases with edge blurring. Image quality is better with the proposed method than that obtained by averaging the three free breathing acquisitions and similar to that obtained in breath hold (*Table 1*). Moreover cardiac muscle intensity is the most homogeneous with the described method and edges are the sharpest (*Fig. 3*).

DISCUSSION & CONCLUSION: Thanks to GRICS reconstruction and heart rate prediction, systolic black blood images have been obtained from free breathing acquisitions. For the sake of comparison with breath hold images, the matrix size has been restricted to 256 but can be easily extended to 384 or 512, as breath holding, and thus acquisition time, are no longer limits.

	Image entropy (less is better)			Gradient entropy (more is better)		
	Average	GRICS	Apnea	Average	GRICS	Apnea
Subject 1	4.155	4.086	4.101	3.171	3.217	3.235
Subject 2	3.971	3.918	3.944	2.967	3.074	3.095
Subject 3	3.916	3.847	3.966	2.879	3.072	3.016
Subject 4	4.151	4.118	4.221	3.182	3.275	3.186
Subject 5	3.837	3.767	3.775	2.918	2.957	2.976

Table 1: Quantitative assessment of image quality

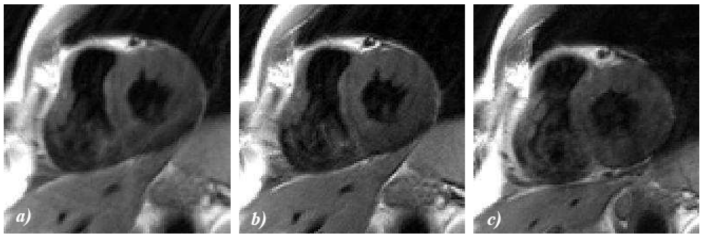

Fig. 3: Black-blood short axis systolic imaging acquired in free breathing, with a) averaged and b)GRICS reconstruction, and c) in breath hold.

These images would be helpful in depicting heart wall details, such as for instance fatty infiltration in the right ventricle wall occurring in arrythmogenic right ventricular cardiomyopathy [5].

REFERENCES: [1] Simonetti *et al.*, Radiology 199: 49-57 (1996); [2] Oster *et al.*, ICASSP: 513-516 (2008); [3] Odille *et al.*, IEEE TBME 54: 630-640 (2007); [4] Odille *et al.*, MRM 60: 146-157 (2008); [5] Tandri *et al.*, JMRI 19: 848-858 (2004).