GATED MAGNETIC RESONANCE IMAGING OF CARDIAC MORPHOLOGY IN OBESE ZUCKER RATS

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Abstract: Effective gating using ECG during small animal model cardiac MR minimises the influence of cardiac motion and suppresses radiofrequency interference. In this paper, we present a simple device to remove on-line MR's noise components from rodent's collected ECG, detection of all R-peaks and generation of trigger signal for fast cardiac MR sequences in real time. A feasibility study is performed on 3 types of rats (normal, obese and hypertensive rats) using different MR sequences and 2 signal processing techniques to evaluate the capability of the gating system we have proposed.
The proposed signal processing methods are based on conventional low pass filtering and on non linear pass band filtering, and have been tested on small rodents ECG signals acquired during MRI scans in 2T magnetic field intensity. The results showed an efficient gating signal and good quality images, using non linear pass band filter, during the three tested imaging sequences (SE, SE and IRSE).

Introduction

The Electrocardiogramm's (ECG) acquisition during MR examinations represents an important challenge due to the interference of the hostile MR environment (Gradients, RF pulses, magnetic field…..) which causes alteration of the signal shape and oscillations of the signal baseline. ECG acquisition becomes more difficult when it concerns small animal such as rodents where the ECG signal has lower magnitude with a very fast and highly variable heart rate depending on the animal size and its health situation.

Arterial hypertension and obesity are considered as major risk factors for cardiovascular diseases. Their genetic and pathophysiological aspects have been studied for more than 50 years in rats, which are reference models in this field allowing studying and monitoring of both obesity and arterial hypertension [1]. Non invasive examinations, such as MRI applied to obese and hypertensive rats offer a unique analysis opportunity to monitor normal and pathological 10 slices of 2-3 mm thickness were acquired with an in plane resolution of 200 µm with the delay after trigger set to 5ms.

cardiovascular properties. Acquisitions of good quality MR images of the cardiovascular system need to be ECG gated, thus requiring a robust method to record ECG in rats in the MR environment. Recently, several studies are focused on presenting new techniques of ECG acquisitions and denoising during gated MR sequences [2], [3], [4].

In this paper, we will describe a feasibility study performed on 3 types of rats (normal, obese and hypertensive rats) using different MR sequences to evaluate the capability of the gating system we have proposed.

Materials and Methods

Animal preparation:
Healthy Fisher and fatty Zucker rats were obtained from Charles River Laboratory. Hypertensive (HT) rats carrying the CETP gene were obtained by backcross between Fisher rats and genetically hypertensive LH rats from Lyon, France [1].

The rats were anesthetized by intraperitoneal injection of sodium pentobarbital (50 mg/kg, Sanofi).

The ECG detection consisted on Einthoven method using Neonatal Electrodes (3M RedDot,). The mass connection was placed on the right foot (RF) electrode and the derivation connections were placed on left arm (LA) and right arm (RA) electrodes. Epilating paws and use of a contact gel (ref) increase magnitude by 20-30%.

MRI:

This study was conducted on a 2T, superconducting OXFORD 85/310 horizontal cryomagnet, with a 50 mT.m-1 gradient system. A home made bird cage coil adapted to fatty and big size rats was used.
3 types of MR sequences, Spin Echo (SE), Fast Spin Echo (FSE) and Inversion Recovery Spin Echo (IRSE), inducing different types of contamination on ECG signal were tested.
Acquisition parameters are: TR/TE=400/15ms, 1700/15ms and 900/30 ms for T1-weighted SE, T2-weighted FSE and IRSE respectively.

ECG gating:
Two techniques, Module 1 and Module 2, of signal processing and gating were tested during the

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experimentations. Module 1 is based on a manual adjustment of the trigger threshold while Module 2 consists of a non linear pass-band filtering without threshold adjustment.

The algorithm for noise removal and for signal generation used for image sequences synchronisation included the following steps : 1) computation of the squares of first and second derivatives of a given signal, 2) specific smoothing (zero-phase filter) of each square derivative, 3) application of a numerical Schmitt trigger with relative low thresholds on the sum of smoothed squares derivatives.

An updated threshold, applied on this sum provided information on the occurrence of the R waves and lead to the triggering signal which was conducted to the MR system computer via a home made converter box.
The bloc diagram of the gating module is showed figure 1:

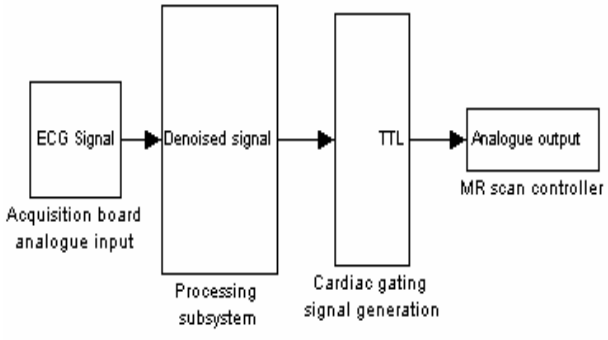

Figure 1: Bloc diagram of real time gating model.

On the diagram the different steps of the MR gating real time process are represented. The acquisition subsystem gets ECG signal analogue data from the board. The signal processing subsystem uses the selected module to diminish or eliminate MR interferences. The gating subsystem then derives from the denoised signal a TTL signal defining gating acquisition windows. At the end, the output subsystem sends the digital TTL signal to the analogue output of the board which is connected to the sequencer of the MR system.

Data analysis:
From each studied rat, a sample signal of each sequence/module pair was selected. Thus, with 3 sequences and 2 modules, the analytical study was achieved on 8 signals of one second duration each.
To evaluate the performance of each module on signal quality as well as gating efficiency, the following parameters were calculated before and after processing, i.e., PrP and Pop, for each sample signal: Signal to Noise Ratio (SNR) in dB, the Heart Rate (HR) in bpm and the shift between initial R peak and the denoised one (Shift) in ms. We also get parameters concerning the detection of R waves, i.e. False Trigger (FT), False Negative (FN), Sensitivity (S), Prediction (P) and detection rate (T).
FT: TTL signal that doesn't correspond to an R wave.
FN: R wave which has not given a TTL signal (missed detection).
C: total number of R waves per second at initial signal.
S: 1 - (FN/C); P :(C-FN)/ (C-FN+FP); T: 1-(FP/C).

The detection rate 5 (T) using module 2 for sophisticated MR sequences such as FSE and IRSE had a percentage of 100%, while same signals studied with module were gated with an efficient detection rate of 66% and 75% respectively.

For this reason, we will only show values obtained using module 2.

Results and Discussion

We investigated 6 rats, healthy (N=2, mean weight 220g, mean heart rate 400 bpm), Zucker (N=2, mean weight 620 g, mean heart rate 200 bpm) and HT (N=2, mean weight 420 g, mean heart rate 200 bpm). ECG derived and gating parameter values are listed in table 1.

Table 1: Signal parameters values before and after proccesing for each sample signal using module 2.

Signal Rat _ Sequence		SNR (dB)	HR bpm	Shift ms
Healthy_ SE_	PrP	-	420	
	PoP	-	420	35
Healthy_FSE	PrP	-	420	
	PoP	-	420	35
Zucker_SE	PrP	12.04	240	
	PoP	22.49	240	35
Zucker_FSE	PrP	2.27	180	
	PoP	-	180	35
HT_IRSE	PrP	3.02	240	
	PoP	16.32	240	35

Comparing results from healthy and pathological rats, healthy rats got a faster cardiac rhythm and HT rats present smaller magnitude and larger QRS complexes.
The results corresponding to these observations are illustrated on the real time recorded scope and on appropriated images (figures 2 to 3). The gated images of figures 2(c) and 3(c) are obtained using the gating signals of figure 2(a) and 3 (a) respectively.

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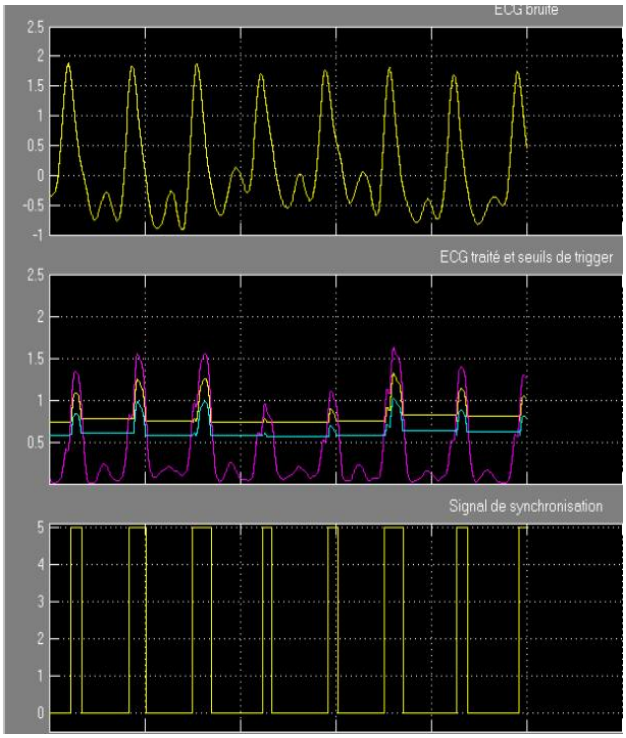
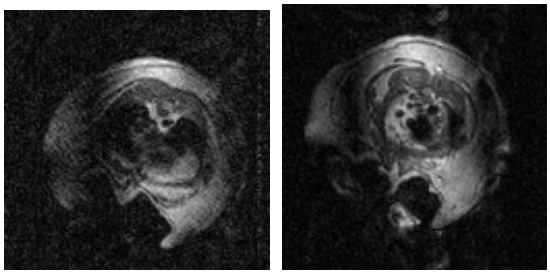


Figure 2.a: Gating during FSE of Healthy rat (420 bpm) using Module2.
1) Rat ECG signal Recorded during Gated FSE Sequence (1s duration); 2) Denoised signal & 2 Schmitt's Trigger thresholds; 3) TTL gating signal derived from the denoised signal.



2.b: Non gated FSE of Healthy rat

2.c: Gated FSE of Healthy rat

Signal quality
There was an important reduction of noise level resulting in SNR increase while using Module 2. In contrast, the noise level remains unchanged with Module 1. With Module 2, the signals mean increases due to baseline stabilisation by filtering. This gives a minimum set to zero while Module 1 keeps negative minimum values.

Resulting shifts for each module are close to fixed value (10 ms for Module 1 and 35 ms for Module 2). The value of 35 ms obtained with Module 2 doesn't match the introduced delay time of the RF trigger during MR sequences (3-10 ms). This may induce a shift in the cardiac cycle for the acquired image gated using module 2.

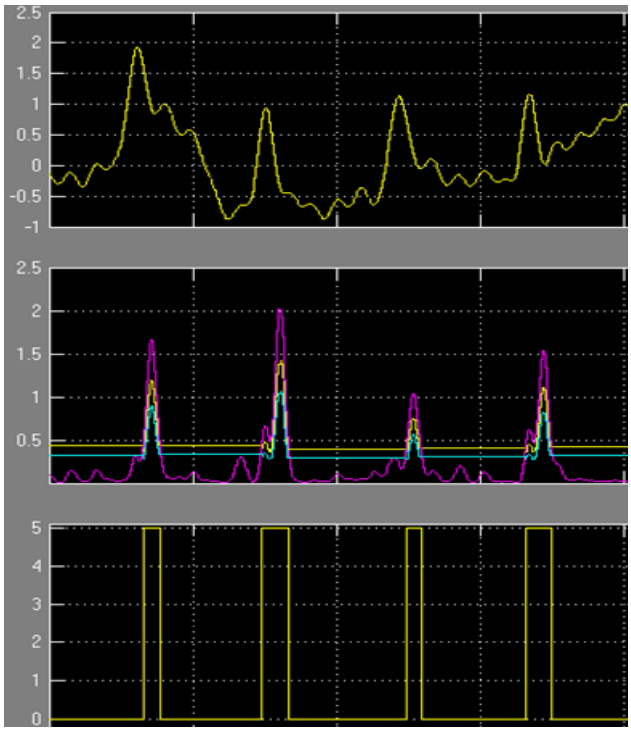
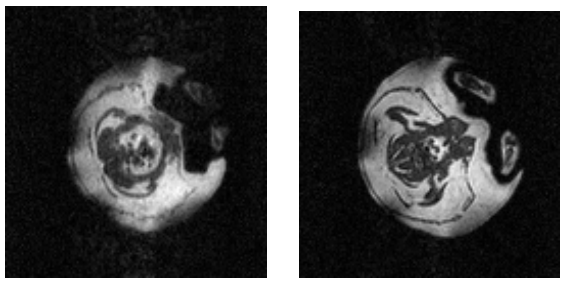


Figure3.a: Gating during SE of Zucker rat (240 bpm) using Module2.
1) Zucker ECG signal Recorded during Gated SE Sequence (1s duration); 2) Denoised signal & 2 Schmitt's Trigger thresholds; 3) TTL gating signal derived from the denoised signal.



3.b: Non gated SE of Zucker rat

3.c: Gated FSE of Zucker rat

Images:
Compared to non gated images, much more details and fewer motion artefacts are observed after gating. Figure 3(c) show gated SE slice in a Zucker rat, where the aortic arch and the carotids bifurcations are clearly depicted.

Sequence effet:
For gated FSE, module 1 is less efficient than module 2 while imaging Zucker rats. In these cases, only half of the R peaks were detected with a false trigger percentage of 30% as shown in figure 4 (a). Using module 2 for the same case we have a better successful detection rate (see figure 4b) where all R waves were correctly detected.

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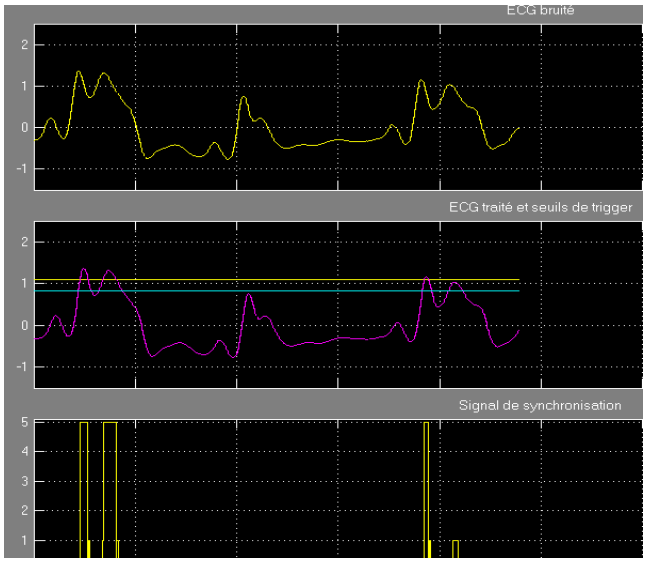

Figure 4.a: Gating for Zucker FSE (Module1)

Figure 4.b: Gating for Zucker FSE (Module2)

1) Rat ECG signal Recorded during Gated FSE Sequence (1s duration); 2) Denoised signal & 2 Schmitt's Trigger thresholds; 3) TTL gating signal derived from the denoised signal.

Conclusions

To conclude, using our system, an efficient trigger signal for image synchronization was extracted from the contaminated ECG in real-time. Good quality gated MR images were obtained with better resolution and fewer cardiac motion artifacts.

This preliminary study shows the feasibility of the proposed method. It still need more developments in term of signal and imaging such as improving the user interface with real time display of gating options (Heart rate, R-R duration, Systole/Diastole....) and the extraction of respiratory signal to validate cardiorepiratory gating in MR imaging. Finally, we should go to a higger image resolution (100 µm), a process that will induce more MR interferences and require a more stable gating system to apply to any MR exam.

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