Foetal cardiac gating for MRI: a Wavelet Transform based approach for the real-time detection of foetal R-waves

P. Di Giovanni[1], A. R. Allen[2], T. S. Ahearn[1], and T. W. Redpath[1]

[1]Radiology, Aberdeen University, Aberdeen, Scotland, United Kingdom, [2]School of Medical Sciences, Aberdeen University, Aberdeen, Scotland, United Kingdom

INTRODUCTION

The non-invasive nature of magnetic resonance imaging plays an important role in the assessment of foetal related diseases. Within the circulatory system of the foetus physiological and anatomical details can be extracted by imaging the morphology of the heart and by mapping the flow into the aortic wall or into the umbilical vein. For this purpose a MRI scan needs to be triggered with the foetal heart cycle. The ECG obtained from the abdomen of a pregnant woman is a combination of the maternal and foetal PQRST complex. A robust signal processing methodology is needed for the real-time detection of the foetal R-waves. By using ungated echo planar imaging, the acoustic noise generated by the gradient system would be over the tolerated threshold for the foetal auditory system; a quieter sequence, such as ECG-gated segmented k-space FLASH, which allows the acquisition of few k-space lines for each foetal heart cycle, is a preferable choice for this application. In this case the computational time between the detection of a foetal R-wave and the trigger of the scan needs to be within about 10ms: this would allow taking an image of the foetal heart during its contraction phase. The Discrete Wavelet Transform (DWT) has been shown to be particularly suitable for the analysis of ECG signals[1]. The DWT has also been used for de-noising and for the suppression of the breathing motion artefact in the ECG signals[2]. If an ECG signal is decomposed by DWT, the result is a series of coefficients associated with low and high frequencies of the signal; this information can be elaborated in a way to distinguish between the maternal and foetal R-waves[3]. The purpose of this work is to investigate the possibility of real-time detection of the foetal R-waves by Wavelet Transform analysis.

MATERIALS AND METHODS

On a CPU working at 2.80 GHz the Wavelet Toolkit (MATLAB, The MathWorks, Inc.) was used to analyze two types of maternal abdominal ECG: 1. Four synthetic signals of 5 seconds each (Figure 1.a) generated from adult ECGs with a sampling rate of 100Hz. 2. Four real abdominal ECGs of 10 seconds each (Figure 1.b) obtained from a biomedical database[4] with a sampling rate of 250Hz. The detail coefficients obtained from a first level DWT decomposition of the complex ECG contain the information related to the high frequencies present in the signal (noise, foetal and maternal R-waves); within these the pattern associated with the foetal R-waves was identified and stored during a set-up phase. The signals were then processed by DWT using different wavelet patterns and a simulation of real time ECG gating performed by processing the data progressively. The algorithm compares each new sample with the stored template and, depending on how well they correlate, decides whether or not the scan should be triggered. Analysis was performed both with and without a de-noising component.

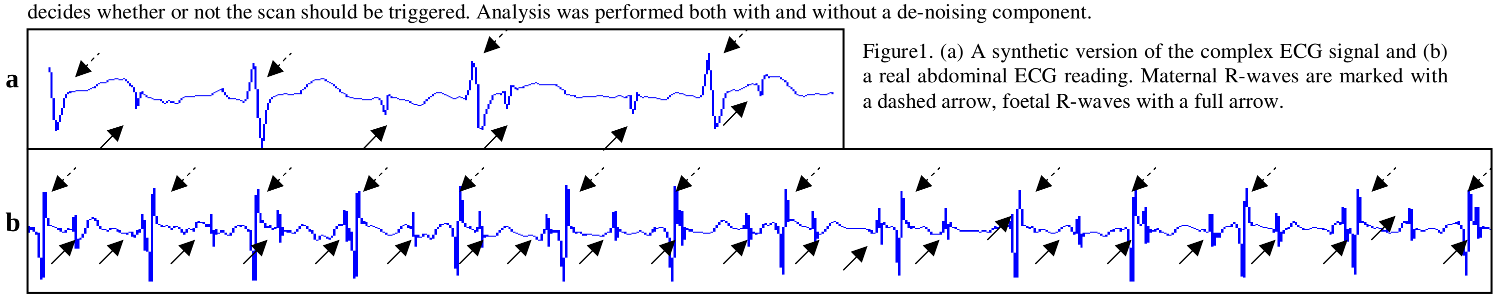

Figure1. (a) A synthetic version of the complex ECG signal and (b) a real abdominal ECG reading. Maternal R-waves are marked with a dashed arrow, foetal R-waves with a full arrow.

RESULTS

The algorithm has been tested with both synthetic and real signals; the output of the software has been analyzed and classified according to Table 1. The overall detection accuracy has been estimated on the basis of the number of foetal R-waves correctly detected for both groups of signals. We found that the optimum wavelet to use was the Biorthogonal 2.6; this has a symmetrical pattern that matches particularly well the foetal R-wave envelope and this is reflected in the values of the detail coefficients at the time location of the R-wave. The detection accuracy of the algorithm on the synthetic data was found to be 95% while for the real data it was found to be 89%. Computational time was 15ms if the ECG was not de-noised, otherwise it takes 31 ms.

DISCUSSION

The algorithm works well for the synthetic signals giving only one undetected foetal R-wave which was masked by the stronger maternal QRS complex. Within the real data there are several undetected R-waves, three of these occur immediately after a maternal R peak; this is a location of the maternal heart cycle which applies a strong distortion to the foetal R-wave, making its detection difficult. The false positives are due to strong gradients in the complex ECG: these are generated either from a noisy component or from a particular combination of the maternal and foetal heart cycles. In future applications the algorithm will be run on dedicated hardware, this would enable a faster processing time and therefore an overall computational time comparable with the time width of the foetal R-wave. The Wavelet Transform has been confirmed to be an efficient tool for the detection of singularities associated with the foetal R-waves. The ECG signals that we have used do not include the type of distortion generated from the static magnetic field (flow-induced potentials[5]) and from the gradient system present in the MRI bore; in that case we expect to see significant changes in the envelope of the complex ECG. This would probably deteriorate the detection accuracy, require further signal filtering and therefore increase the computational time needed for the triggering of the fast imaging sequence. To be noticed that it is not necessary to detect each single R-wave, if one is missed the next one is awaited and the length of the scan is delayed of one foetal heart cycle.

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Type of signal	**Synthetic**				**Real**			
Number of foetal R-waves	6	5	5	6	22	22	22	22
Number of foetal R-waves masked by maternal R-wave	1	0	0	0	0	0	0	4
Number of foetal R-waves correctly detected	4	5	5	6	22	19	18	16
False positive	0	0	0	0	0	2	2	1
Number of foetal R-waves undetected	1	0	0	0	0	3	4	2

Table 1. For each signal is listed the statistical output given by the software