DEDICATED MR ECG AMPLIFIER

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INTRODUCTION:

Cardiac MRI is highly dependant on the accuracy of electrocardiogram (ECG) signals and on the QRS detection algorithm. However, ECG acquisition is problematical in the MR environment. Large artifacts may be superimposed on ECG signals due to the main magnetic field, the gradients of magnetic field and radiofrequency pulses. The introduction of conductive material (amplifier and wires) becomes crucial due to safety issues (1). The ferromagnetic parts of ECG sensors, when placed in the field of view (FOV), generate artifacts on images. If smaller surfaces were exposed to electromagnetic fields, less radiofrequency interferences were expected. Our hypothesis was that a dedicated ECG amplifier, miniaturized and non-ferromagnetic, based on microelectronic technology allowed safe and accurate ECG acquisition. Better performances were expected in terms of QRS complex detection and of artifact suppression on both images and ECG signals, compared to conventional standard ECG sensors.

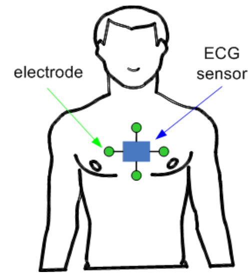

Fig. 1: Electrode positioning with integrated ECG sensor during MRI.

MATERIAL AND METHODS:

We developed and implemented an integrated ECG acquisition system mainly consisting of amplifiers and filters, with two recording channels. At the final stage, the ECG signal was modulated and converted into an optical signal to be connected to a MR patient monitor (Schiller Médical, France) and then recorded with existing setups (2). The circuit was fabricated in standard 0.35 µm CMOS technology, featuring low power (1 mA @ ±1.5V), a 3.8 x 2.9 mm^2 surface and CMRR of 95 dB. It is necessary to reduce the length of the acquisition wires (3) and to position the ECG amplifier as close as possible to the heart (figure 1). For this prototype, the same packaging was used as for standard ECG sensors. The length of the acquisition wire was about 10 cm. Two healthy volunteers underwent a specific MR examination. ECG signals were simultaneously acquired with the ECG chip and a standard ECG sensor (Schiller Médical, France). 1040 QRS complexes were recorded and the performance of the new system was compared to commercially available systems.

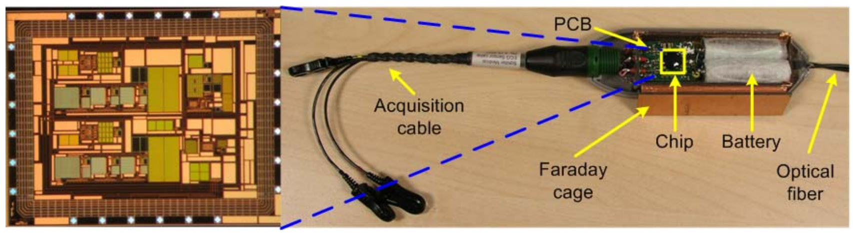

Fig. 2: Microphotograph of the fabricated ECG sensor and photo of the prototype tested in an MRI environment.

RESULTS:

No artifact is visible on MR images due to the presence of the ECG amplifier chip during several sensitive sequences (EPI, Gradient Echo and SSFP at 1.5T) (figure 3). ECG traces simultaneously acquired with standard technologies and integrated technologies appear very similar. During MR sequences, artifacts on the ECG due to gradient switching is quite equivalent (figure 4). This result was predictable since the surface exposed to the electromagnetic field was the same. The statistical results regarding QRS complex detection is shown in table 1.

Tab. 1: Statistical results regarding QRS complex detection.

	Sensitivity	positive predictive value
ECG chip	99.04%	89.79%
Standard sensor	98.17%	77.10%

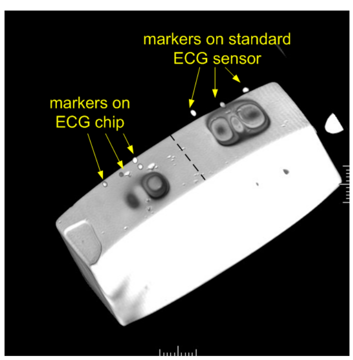

Fig. 3: Artifact on MR images caused by the ECG sensor. Comparison between the ECG chip and the standard sensor. The artifact on the left is mainly caused by the battery.

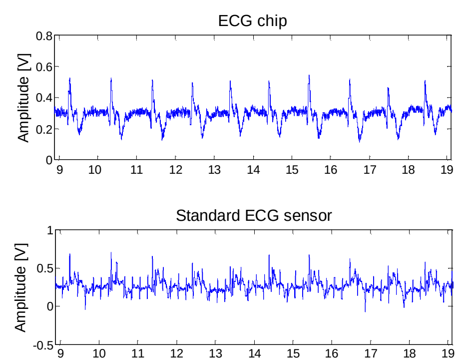

Fig. 4: Artifacts on the ECG. Comparison between the new ECG chip and the standard ECG sensor. Sequence GE-EPI, TR=100 ms, FOV = 99 cm, matrix 364x352.

DISCUSSION:

Using microelectronic technology allows obtaining a non magnetic and very small ECG sensor that could be placed in the FOV. The experimental results, showing better sensitivity and positive predictive value of QRS detection than with a standard ECG sensor, suggest a number of new applications. The acquisition wires can now be reduced to 1-2 cm making safe ECG acquisition in a stronger field possible. ECG classification also becomes possible since the bandwidth of the ECG signal can be increased. The higher the bandwidth, the more the delay is reduced, which allows a more precise and robust synchronization of imaging sequences with the ECG.

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