Diagnostic Value of the Electrocardiogram During Cardiac MRI Stress Testing

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Introduction
In addition to gating an MR scan, a second purpose for the ECG during MRI is for monitoring during cardiac stress tests. However, the diagnostic information of ECG waveforms obtained during a MR examination is hampered by two factors. First, the ECG waveform is disturbed by artifacts from the MR environment due to the main magnetic field [1], RF pulses and fast switching gradient fields. Second, for patient safety reasons the MR environment requires special, MR compatible monitoring equipment, which may not satisfy the standards for diagnostic ECG equipment [2]. The purpose of this study was to determine the diagnostic value of the ECG obtained at 1.5 Tesla during a stress test.

Methods
In 5 patients (4 with normal ECG, 1 with known ST segment elevation under stress) a single ECG lead parallel to the electrical axis of the heart was recorded (1 kHz sampling rate) during a MRI dobutamine stress test with doses from 5 to 40 μg/kg/min. In 3 patients (normal ECG) using the same stress test protocol the vectorcardiogram (VCG) in the frontal plane were digitized at 1kHz using a MR compatible VCG system [3]. All recordings and MR imaging was performed on a 1.5 T MR scanner (Philips Gyroscan ACS-NT). Specific diagnostic features of the ECG were analyzed.

Results and Discussion
The ECG sensors in MR compatible monitoring systems include additional filtering to deal with MR related artifacts (i.e. 1-20 Hz bandpass). Further, non standard lead placements are recommended. Thus, these monitoring systems do not conform to the set standards for monitoring [2]. The effect of the B0 field for specific ECG parameters is summarized as followed:

- **P-wave**: In patients exposed to a magnetic field of 1 T or more, the P-wave amplitude, axis and time intervals related to the P wave cannot be measured [2] with diagnostic accuracy.
- **QRS-complex**: The QRS complex can be identified even at 2 T. This and other studies have shown that the R-peak amplitude is preserved in the ECG obtained inside a magnet. Despite the fact that the electrical axis is preserved (9° ± 7° angle difference) the beginning and termination of the QRS loop are disturbed as shown in Fig. 1. The correlation of the ECG waveforms from inside and outside the B0 field showed that the correlation factor from a 10 ms sliding window dropped below 0.75 outside an interval of -31 ms to +35 ms from the R peak. This confidence interval was found to be only 73 ± 17% of the QRS duration.
- **ST-Segment and J-point**: The majority of aortic blood flow occurs during the ST segment. All the large vessels, such as aorta and pulmonary arteries and also the ventricles themselves contribute to the magnetohydrodynamic artifact. The complexity of the flow makes it impossible to predict the artifact waveform. The spectrum of the blood flow artifact overlaps with that of the ST-segment. Fig. 1 demonstrates that the waveform of blood flow artifact is highly dependent on the heart rate, or more precisely on the blood flow velocity and stroke volume. Thus, the ST segment and J-point (Fig. 2) acquired during MRI is not diagnostic.

Conclusions
Heart rate and electrical axis can be derived from the ECG acquired in the MR environment, although heart rate should be analyzed manually in the presence of magnetohydrodynamic artifacts. The onset of the peak amplitude of the first or second major wave after the QRS complex cannot be correlated with the T-wave obtained outside the magnet. The mean maximum amplitude, normalized to the R-peak was 0.87 ± 0.75.

T-wave: The T-wave of the ECG obtained inside an MR scanner is buried below the magnetohydrodynamic artifact. The onset of the peak amplitude of the first or second major wave after the QRS complex cannot be correlated with the T-wave obtained outside the magnet. The mean maximum amplitude, normalized to the R-peak was 0.87 ± 0.75.

Figure 2 J-point amplitude in and outside the magnet.

- **Figure 1** - Frontal plane VCG obtained outside a MR system and at 1.5 T at rest and stress (110 bpm).

**Figure 2** - J-point amplitude in and outside the magnet.