# Real-Time Adaptation of TI and Flip Angles in Inversion Prepared Coronary Angiography

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## Introduction

Preliminary research has shown inversion preparation is the method of choice in contrast enhanced coronary MR angiography (CE-CMRA) using intravascular contrast agents [1]. During a scan that may take up to 30 minutes, the subject's heart rate is never constant. Even in medicamentously adjusted patients, large variations are observed (figure 1). Inversion preparation aims at nulling the longitudinal magnetization of myocardium at the beginning of a scan in each R-R interval. The required inversion time depends on the heart rate and hence varies from one cardiac cycle to the other too. A constant TI as currently used in CE-CMRA results in residual magnetization of the myocardium. This quasi-random signal is referred to as 'physiologic noise' in the following. We implemented an inversion-prepared gradient echo sequence with real-time computation of TI and variable excitation flip angles to ensure perfect suppression of the myocardium at all times during a scan.

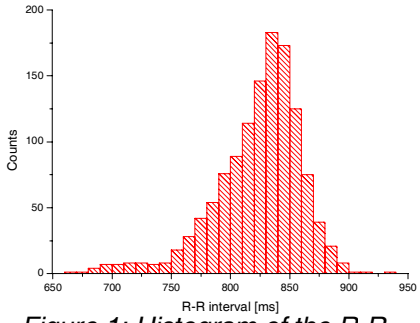


*Figure 1: Histogram of the R-R intervals of a patient during a 15-minute CE-CMRA scan*

## Materials & Methods

A segmented spoiled gradient echo sequence (fig. 2) was implemented on a 1.5 T MR system capable of real-time feedback (Siemens Magnetom Sonata, Erlangen, Germany). During the scan, the macroscopic longitudinal magnetization of blood and myocardium was modelled using the Bloch equations, assuming $T_1$ values of 100 ms and 900 ms respectively. If the last pulse of the excitation train has 90° flip angle, the inversion time that nulls the myocardium at the desired trigger delay *TT* is:

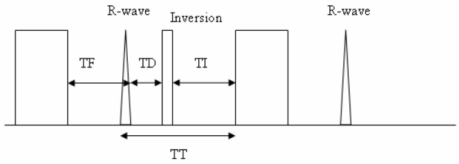


*Figure 2: Sequence timing diagram*

$$TI = -T_1^M \cdot \ln\left[\frac{1+e^{-\left(\frac{TF+TT}{T_1^M}\right)}}{2}\right]$$

, where $T_1^M$ is the relaxation time of myocardium and *TF* the fill time during the last R-R interval. All flip angles used for excitation were also computed in real time, because they depend on the initial longitudinal magnetization of blood if relaxation during the readout train is not neglected. We tested the method in pigs and administered 60 µmol Fe/kg VSOP-C184 (Ferropharm, Teltow, Germany), an iron oxide based blood pool contrast medium with strong $T_1$ shortening. A comparison with conventional inversion prepared acquisition using constant TI and flip angles was performed.

## Results & Discussion

Imaging using real-time adaptation of TI and variable flip angles improves vessel delineation and suppression of myocardium, as figure 3 demonstrates. However, it requires short relaxation times in blood so that its longitudinal magnetization is almost completely restored during the inversion time, independent of the TI value. If this is not the case, physiologic noise just moves from myocardium signal into that of blood. For this reason the method works better in subjects with low heart rates that require longer TI's. Simulation shows that the physiologic noise in a patient with an average R-R interval of 1200 ms with ± 100 ms variation and a $T_1$ in blood of 66 ms is reduced by 95% from about 6% to 0.3%. Only 45% reduction is theoretically achieved at an R-R interval of 800 ms and $T_1$ of 100 ms in blood, as it was the situation in our animal experiments. A greater impact on image quality is therefore expected in human CE-MRA studies.

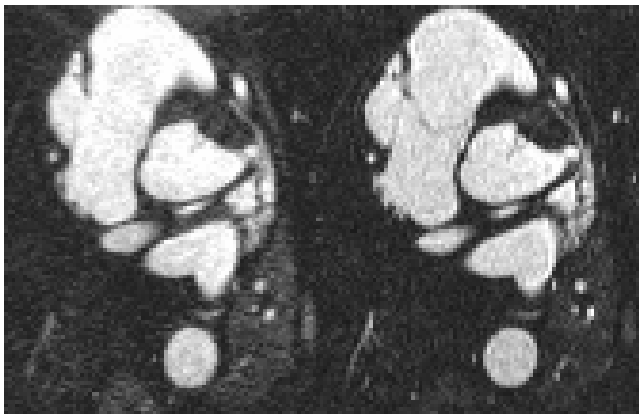

*Figure 3: Image with constant (left) and variable (right) TI and $\alpha$*

References [1] Stuber M et al., JMRI 1999 Nov; 10(5): p. 790-9