Self-Navigated Three-Dimensional Cardiac T_2 mapping at 3T

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Target: Basic and clinical scientists focused on translational cardiovascular research.

Introduction: Cardiac T_2 mapping using a variable T_2 preparation module (T_2Prep) has recently gained attention for its ability to quantify the extent of edema [1]. Due to time constraints, the T_2 maps are commonly acquired as one or several two-dimensional slices, while the underlying pathology has a three-dimensional (3D) structure. The next logical step would therefore be to exploit recent hardware and software advances to directly acquire 3D T_2 maps within a clinically feasible time. An undersampled self-navigated acquisition [2] might allow this, since the navigator and slice planning can be bypassed, while the sequence has 100% acquisition efficiency (compared to ≤50% for respiratory-navigator-gated acquisition). To this end, we developed, implemented and tested self-navigated radial imaging with variable T_2Prep for 3D T_2 mapping at 3T.

Methods: Approval was obtained from the institutional review board and all subjects provided written informed consent. A 3D self-navigated undersampled (20% of the Nyquist criterion) balanced steady-state free precession (bSSFP) sequence (repetition time TR=2.6ms, echo time TE=1.33ms, matrix 128^3, excitation angle 70°) with a spiral phyllotaxis radial 3D trajectory [3] was implemented on a 3T clinical system (Magnetom Skyra, Siemens, Germany). This self-navigated pulse sequence allows for free-breathing acquisitions with 100% scan efficiency, while ECG triggering every 2nd heartbeat and T_2Prep duration TE_{T2Prep}=60/30/0ms lead to a total acquisition time of ~18min with an isotropic spatial resolution of $(1.7mm)^3$. Through Bloch equation simulations (Matlab, The Mathworks, USA), the dependency of the T_2-fitting process on the heart-rate (due to T_1 relaxation) was ascertained. Subsequently, the validity and accuracy of the T_2 fitting was tested in a phantom in which the 'true' T_2 values were previously determined with a spin-echo sequence with variable TE. The 3D datasets obtained with different TE_{T2Prep} were registered using 3D affine registration [4]. The *in vivo* robustness of the T_2 determination was then tested in 10 healthy adult subjects. The resulting datasets were reformatted in a short-axis orientation. The AHA-standard 16-sector segmentation [5] of a basal, mid-ventricular and apical slice of the left ventricle (LV) was applied to study the homogeneity of the T_2 values. Paired Student's *t*-tests with Bonferroni correction for multiple comparisons were applied to test for T_2 differences between segments and slices. The entire LV moycardium was then segmented a sub-endocardial level in Matlab to visually assess the overall T_2 homogeneity. Finally, the sequence was applied for the detection of edema in a 75 year-old male infarct patient after revascularization of his proximal left circumflex artery.

Results and Discussion: The Bloch equation simulations of the pulse sequence demonstrated that the input T_2 value could be accurately fitted from the magnetization M with the empirical equation $[M=M_0e^{-TET2Prep/T2}+0.08\cdot M_0]$, while the fitted T_2 had only a ~3% variation over the common range of expected heart rates (Fig. 1A). The phantom T_2 maps demonstrated high homogeneity and fitting accuracy with the 3D sequence matching the 'true' value to within 1% (Fig. 1B). The volunteer study (Fig.2A,B,D) confirmed the ease of use and furthermore suggested good agreement with previously reported T_2 values at T_2=40.5±3.3ms [6]. The segment analysis showed a slight decrease in T_2 from the base to the apex (43.3±2.0ms vs. 37.4±2.4ms, p=0.002; neither was statistically significant vs. the mid-ventricle at 40.6±2.4ms). Similarly, a slight decrease in T_2 from the inferior towards the anterior segment was observed (42.4±5.3ms vs. 37.2±4.9ms, p<0.001). These modest variations of <15% in the T_2 fitting process in the healthy volunteers may be attributable to differences in noise levels as a function of local coil sensitivity. Simultaneously, differences in instantaneous regional myocardial perfusion (and thus oxygenation) between the base and apex may lead to the observed variations. In the left ventricle of the patient, a region of significantly elevated T_2 (60.4±9.1 vs. 41.0±4.5ms in a remote segment, p<0.001, a 47% increase in T_2) was identified in the infero-lateral myocardium (Fig.2C,E), consistent with the findings on X-ray coronary angiography.

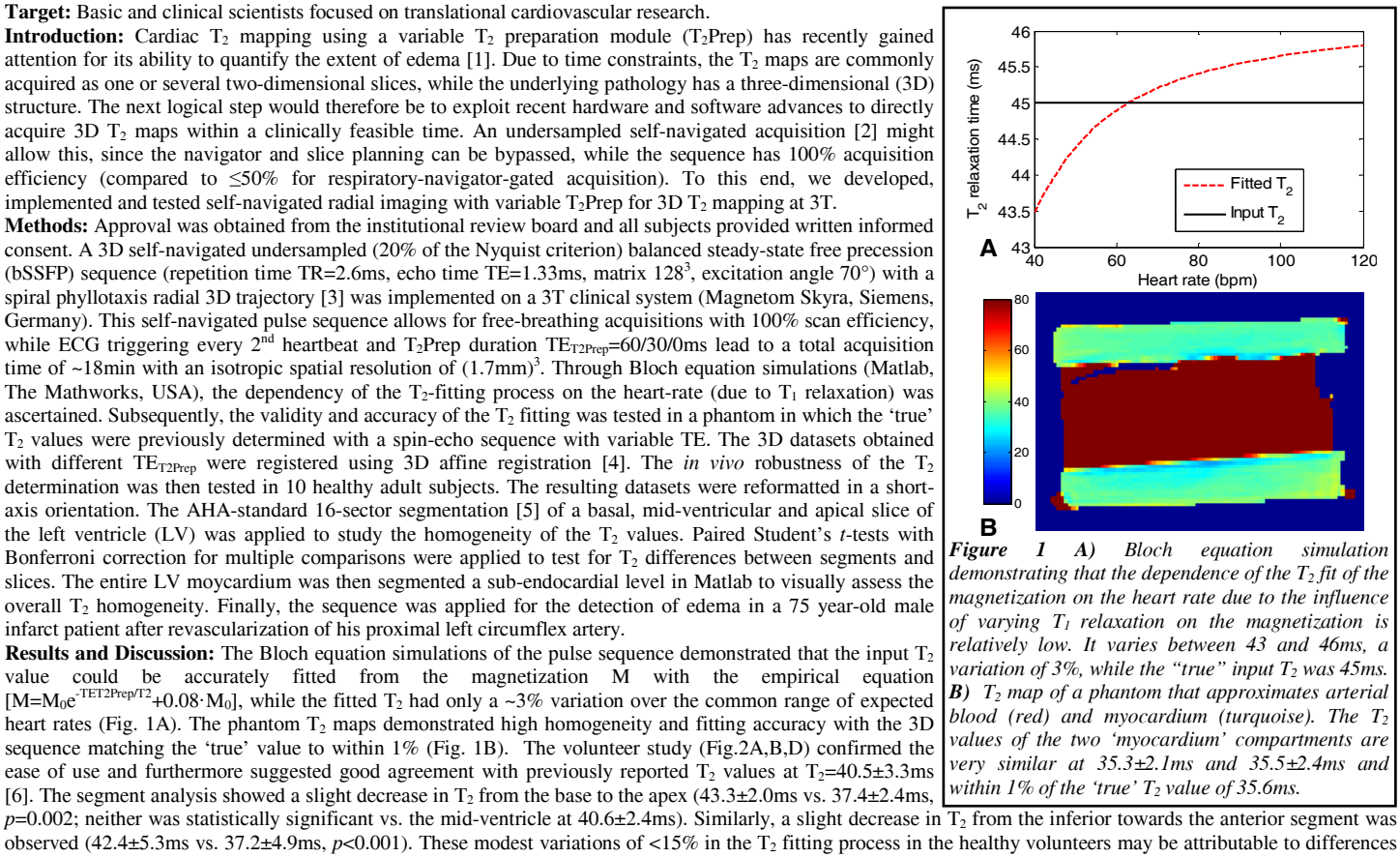

***Figure 1** A) Bloch equation simulation demonstrating that the dependence of the T_2 fit of the magnetization on the heart rate due to the influence of varying T_1 relaxation on the magnetization is relatively low. It varies between 43 and 46ms, a variation of 3%, while the "true" input T_2 was 45ms. **B)** T_2 map of a phantom that approximates arterial blood (red) and myocardium (turquoise). The T_2 values of the two 'myocardium' compartments are very similar at 35.3±2.1ms and 35.5±2.4ms and within 1% of the 'true' T_2 value of 35.6ms.*

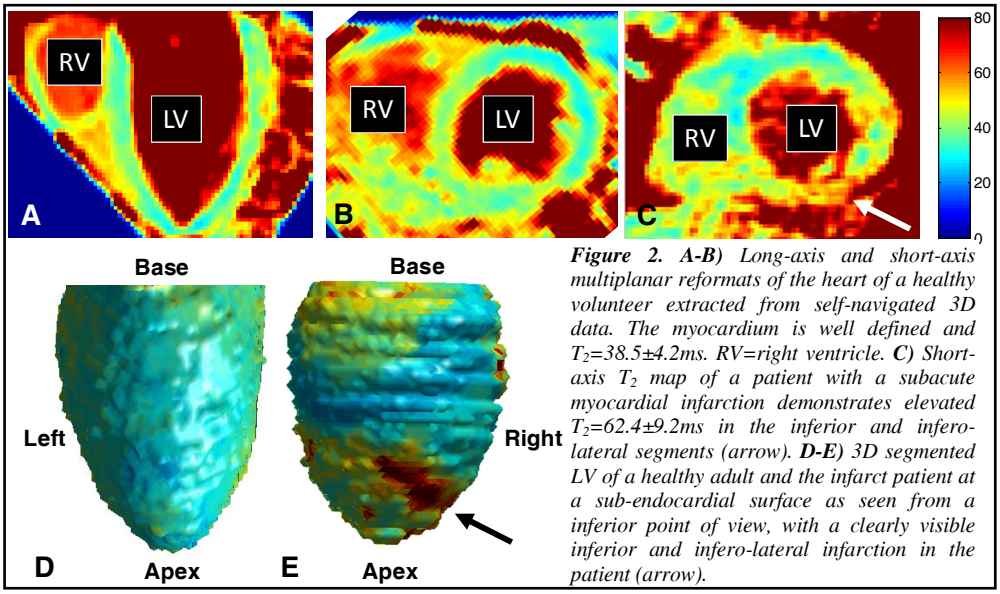

***Figure 2. A-B)** Long-axis and short-axis multiplanar reformats of the heart of a healthy volunteer extracted from self-navigated 3D data. The myocardium is well defined and T_2=38.5±4.2ms. RV=right ventricle. **C)** Short-axis T_2 map of a patient with a subacute myocardial infarction demonstrates elevated T_2=62.4±9.2ms in the inferior and infero-lateral segments (arrow). **D-E)** 3D segmented LV of a healthy adult and the infarct patient at a sub-endocardial surface as seen from a inferior point of view, with a clearly visible inferior and infero-lateral infarction in the patient (arrow).*

Conclusions: The proposed undersampled self-navigated technique for the first time allows the acquisition of isotropic 3D T_2 maps of the whole heart within a clinically feasible time. The accuracy of the T_2 values was confirmed in the phantom, while those in volunteers are consistent with previously reported values. The preliminary patient study demonstrated elevated T_2 in the infarcted region, as expected.

References: **[1]** S Giri et al., JCMR 2009 30;11:56 **[2]** C Stehning et al., MRM 2005 54(2):476 **[3]** D Piccini et al. , MRM 2011 66(4):1049 **[4]** C Studholme et al., Med Image Anal 1996 1(2):163 **[5]** MD Cerqueira, Circulation 2002 105(4):539 **[5]** RB van Heeswijk, JACC Imaging 2012, in press