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A systematic evaluation of three different cardiac T2-mapping sequences at 1.5 and 3T in healthy volunteers

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ABSTRACT

Background: Previous studies showed that myocardial T2 relaxation times measured by cardiac T2-mapping vary significantly depending on sequence and field strength. Therefore, a systematic comparison of different T2-mapping sequences and the establishment of dedicated T2 reference values is mandatory for diagnostic decision-making.
Methods: Phantom experiments using gel probes with a range of different T1 and T2 times were performed on a clinical 1.5T and 3T scanner. In addition, 30 healthy volunteers were examined at 1.5 and 3T in immediate succession. In each examination, three different T2-mapping sequences were performed at three short-axis slices: Multi Echo Spin Echo (MESE), T2-prepared balanced SSFP (T2prep), and Gradient Spin Echo with and without fat saturation ($GraSE_{FS}$/GraSE). Segmented T2-Maps were generated according to the AHA 16-segment model and statistical analysis was performed.
Results: Significant intra-individual differences between mean T2 times were observed for all sequences. In general, T2prep resulted in lowest and GraSE in highest T2 times. A significant variation with field strength was observed for mean T2 in phantom as well as *in vivo*, with higher T2 values at 1.5T compared to 3T, regardless of the sequence used. Segmental T2 values for each sequence at 1.5 and 3T are presented.
Conclusions: Despite a careful selection of sequence parameters and volunteers, significant variations of the measured T2 values were observed between field strengths, MR sequences and myocardial segments. Therefore, we present segmental T2 values for each sequence at 1.5 and 3T with the inherent potential to serve as reference values for future studies.

We show significant differences of myocardial T2, depending on sequence design and field strength. We present segmental T2 values with the potential to serve as reference values for future studies.

1. Background

Myocardial oedema is a characteristic diagnostic finding in acute cardiac pathologies such as myocarditis or myocardial infarction. Cardiac T2-mapping has been suggested as a quantitative approach to oedema imaging, overcoming some of the known limitations of qualitative oedema assessment [1–3]. Accordingly, it may lead to a more objective image interpretation and allow for a more sensitive detection of either diffuse or even subtle changes in myocardial T2 relaxation times, especially in cases of diffuse oedema, where "normal" remote myocardial reference regions are lacking.

One of the main challenges of myocardial T2-mapping is, however, the high intra- and interindividual variability of T2 times, leading to potential difficulties in discriminating between health and disease. While T2 is an inherent tissue property, previous studies reported T2 times ranging from 39 to 62 ms [1–7], depending on sequence design and the field strength. Considering that the difference between remote and oedematous myocardium can be relative small [1,5] and that diffuse tissue changes may be overlooked in the absence of healthy "remote" myocardium, T2 reference values need to be established individually for each sequence and

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field strength. Two studies recently presented reference maps for a T2prep sequence [2] at 3T [3] and for GraSE [1] sequence at 1.5T [8], but no reference values exist for other T2-mapping sequences at 3T and 1.5T.

The goal of our study was therefore to systematically compare three different cardiac T2-mapping sequences in a phantom and in a cohort of 30 healthy volunteers, aiming to analyse the impact of both, sequence design and field strength on estimates of myocardial T2 relaxation times, and to establish global and segmental reference values for each of the analysed T2-mapping sequences at 1.5 and 3T. We chose to compare (i) a T2-prepared single-shot balanced SSFP technique (T2prep) [1,6] that is widely used in cardiac T2-mapping, (ii) a Gradient Spin Echo (GraSE) technique [8,9], and (iii) a Multi Echo Spin Echo (MESE) technique that served as the reference standard.

2. Methods

2.1. Phantom experiments

Phantom experiments were performed at 1.5T (Achieva 1.5T, Philips Medical Systems, Best, The Netherlands) and 3T (Ingenia 3T, Philips Medical Systems, Best, The Netherlands) using a commercially available cylindrical gel phantom (Eurospin test object TO5, Diagnostic Sonar, Livingston, UK) comprising 12 samples with T1 ranging from 313 ms to 1556 ms and T2 ranging from 50 ms to 160 ms, respectively. Mean T2 and standard deviations were measured at 1.5T and 3T in a homogeneous area of the sample comprising approximately 200 voxels. Identical imaging parameters as in the subsequent *in vivo* study were used (see below). For measuring T1, a Modified Look Locker Inversion Recovery sequence (MOLLI) was used because of the widespread use of this sequence in cardiac MR and because of its high reproducibility. Typical imaging parameters were: TR/TE = 2.3/1.15 ms, FA 35°, parallel imaging (SENSE = 2.0), eight single shot balanced SSFP readout trains (inversion, three readouts in consecutive RR intervals, three pause intervals to allow magnetization recovery, re-inversion, five consecutive read-outs).

2.2. Study population

30 healthy volunteers were enroled into the study (14 men/16 women (Table 1). Inclusion criteria for volunteers were: (i) uneventful medical history, (ii) no symptoms of inflammation, (iii) absence of any symptoms indicating cardiovascular dysfunction, (iv) normal cardiac dimensions and function proved by cine CMR. We discouraged alcohol intake and high-intensity sportive activities 24 h before the scans to avoid inflammatory reaction [10] and activity-dependent changes in T2 [11]. Volunteers with history of inflammatory disease including common cold virus in the last four weeks before the scans were excluded from the study [12].

The study was approved by the local ethical committee and written informed consent given by all volunteers. All experiments were performed in compliance with the Helsinki Declaration.

2.3. CMR examination

Each subject participated in two cardiac MR examinations in the morning of the same day. The examinations were performed with a 1.5T (Achieva 1.5T, Philips Medical Systems, Best, The Netherlands) and a 3T (Achieva 3T, Philips Medical Systems, Best, The Netherlands) system in a randomized order. The examination with the 1.5T system was performed using a 5-channel cardiac phased array receiver coil and a 4-lead vectorcardiogram. The examination with the 3T system was performed using a 6-channel cardiac phased array receiver coil and a 4-lead vectorcardiogram. A cardiac-triggered Double-Angle B1 calibration scan [13] was acquired to achieve uniformity in flip angle across the user-defined shim volume and to improve static field uniformity.

Table 1
Characteristics of the volunteers.

Parameter	Result
Number	30
Females/males	16/14
Age [years]	36 ± 13
Age group 20–39 years	22
Age group 40–59 years	5
Age group 60–79 years	3
Height [cm]	176 ± 9
Weight [kg]	73 ± 14
Body mass index [kg/m2]	23 ± 3
Body surface area [m2]	1.9 ± 0.2
Heart rate [min-1]	62 ± 13
LV[a] enddiastolic volume [ml]	153 ± 39
LV enddiastolic volume index [ml/cm]	0.8 ± 0.2
LV ejection fraction [%]	61 ± 5
LV mass [mg]	94 ± 27
LV mass index [mg/cm]	0.5 ± 0.1

[a] LV—left ventricle.

2.4. Cine imaging

SSFP cine images were obtained during repeated breath-holds in two long axes and in a stack of short axes (SAX) covering the left ventricle (LV) to rule out wall motion abnormalities and allow for cardiac chamber quantification. Imaging parameters were for 1.5 T: repetition time (TR) 28 ms, echo time (TE) 1.4 ms, flip angle (FA) 60°, field of view (FOV) 343 × 380 mm^2, matrix 256 × 256, slice thickness 8 mm, 50 cardiac phases and for 3 T: TR 28 ms, TE 1.4 ms, FA 45°, FOV 360 × 428 mm^2, matrix 320 × 320, slice thickness 8 mm, 50 cardiac phases.

2.5. T2-mapping

For T2-mapping, data were acquired in a basal, midventricular, and apical SAX plane using three different T2-mapping sequences: (i) a T2prep technique [1,6], (ii) a Gradient Spin Echo technique with and without fat saturation (GraSE$_{FS}$/GraSE), and (iii) a Multi Echo Spin Echo (MESE) technique that served as the reference standard. We chose to evaluate the influence of a fat saturation pulse on T2 times acquired with GraSE because we expected the EPI readouts to cause more significant chemical shift artefacts compared to the other two sequences. For T2prep, GraSE and GraSE$_{FS}$, double measurements were performed for both scans. The three sequences were ECG triggered and had the following parameters: T2prep: TR/TE = 2.3/1.15 ms, FA 35°, parallel imaging (SENSE = 1.6), TE's of the T2prep pulse: 0, 25, 50, 75 ms and breath hold (scan duration about 12 s); GraSE: TR = 1 heartbeat, 9 echoes (TE$_1$ = 15 ms, delta TE = 7.7 ms), FA 90°, parallel imaging (SENSE = 2), EPI factor = 7, BlackBlood-prepulse and breath hold (scan duration about 14 s); MESE: TR = 1 heartbeat, 9 echoes (TE$_1$ = 12 ms, delta TE = 5.8 ms), FA 90°, parallel imaging (SENSE = 2), BlackBlood-prepulse and navigator gating (mean scan duration about 5 min). The longer echo spacing for GraSE sequence is caused by the EPI readout. The difference of the shortest TE between GraSE and MESE is negligible with 3 ms Due to given SAR constraints, only 2 instead of 4 refocusing pulses were used for the T2prep pulse at 3T. For T2prep, we used composite refocusing pulses (90°x, 180°y, 90°x) to compensate for

[1] Abbreviations: GraSE: Gradient Spin Echo; HV: healthy volunteers; MESE: Multi Echo Spin Echo; MOLLI: Modified Look Locker Inversion Recovery sequence; T2prep: T2-prepared SSFP