Reproducibility of Whole-Body Variable Flip Angle T1 Mapping Using Only Two Flip Angles

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Synopsis

Keywords: Quantitative Imaging, Whole Body, T1-mapping

We investigate the feasibility of whole-body (WB) variable flip angle (VFA) T1 mapping using linear least squares fitting with only two flip angles (FAs) in order to obtain WB T1 maps within a clinically viable timeframe. This could enable its use as an imaging biomarker in metastatic cancer. We assessed the agreement across eight subjects in a variety of abdominal tissues between T1 estimates fitted using eight FAs and just 2 FAs. We found that VFA T1 mapping can be achieved by acquiring only two FAs with minimal loss to precision, providing the lower FA is between 2.5° and 7.5°.

Introduction

Assessing the response to new cancer agents is challenging for conventional imaging methods that rely upon evaluation of size changes as a marker of response. Alternative methods of assessing drug efficacy are necessary. One possibility is T1 mapping, as T1 relaxation time is known to differ between tumour and benign tissue. Moreover, changes in this quantity have been observed in cancers during therapy[1–3]. Variable flip angle (VFA) T1 mapping[4–6] is a rapid quantitative T1 measurement technique widely used to acquire 3D T1 maps of the whole-brain in a clinically feasible time. VFA estimates T1 values by acquiring multiple spoiled gradient echo acquisitions, each with different excitation flip angles (FAs), which can then be used to derive a T1 map via linear least squares (LLS) fitting.

Due to the large area of coverage in whole-body (WB) examinations for diseases like metastatic cancer, it is usually necessary to acquire a minimum of three anatomical stations, depending on the size of the field of view (FoV). Typically, 8-10 FAs are acquired for each anatomical station in VFA examinations, although in the brain it has been shown that this can be reduced to just two[7,8]. While T1 mapping has been studied extensively in the brain[9–12] and the heart[13–16], abdominal T1 quantitation poses unique challenges. Namely respiratory motion, and the need for a large field of view (FOV) coverage. As a result, obtaining reliable abdominal T1 maps within a time-frame acceptable to patients has to date not been reported. In order to obtain WB T1 maps within a clinically viable timeframe, we investigate the feasibility of estimating T1 maps in the abdomen using LLS fitting with only two FAs.

Method

Study Design

Eight healthy subjects underwent three WB test-retest VFA mDixon sequences on a Philips 3T Ingenia: voxel size 2.56 × 2.56 × 5 mm, TR = 4 ms, TE = 1.15 ms and 2.3 ms, matrix size 192 × 192 × 120, with breath holds. Eight FAs were collected (2.5°, 5°, 7.5°, 10°, 12.5°, 15°, 17.5°, 20°) at each anatomical station. Transmit RF amplitude (B1) maps were collected for each FoV in order to perform B1 correction on the mDixon data: voxel size 5.13 x 5.13 x 3 mm, TR = 20 and 100 ms, TE= 2.8 ms, FA=60, matrix size 96 × 96 × 100, no breath holds.

Image Analysis

T1 maps were calculated from B1 corrected in phase images using LLS fitting. Maps calculated from all eight FAs were then used as a reference point to compare maps calculated from just two. Regions of interest (ROIs) were drawn in a variety of tissues, the summary statistics of which can be seen in Table 1, along with those of a second study for comparison. For each tissue studied, a single ROI was drawn in the acquisition plane of each of the 24 scans (8 subjects, each with 3 test-retest examinations).

Having three test-retest scans across eight subjects allows for a within-subject measure of both within- and between-fitting agreement, as set out by Bland et. al[17]. The repeatability coefficient (RC) is the number that, if you make two measurements of the same subject under the same conditions, the difference between those two measurements will be less than the RC in 95% of cases[17,18]. The reproducibility coefficient (RDC) is the same as the RC, except for measurements made under different conditions[17,18] (e.g., using a different fitting method). In both cases, the smaller the coefficient is, the better.

Results and Discussion

The RC was calculated for all fittings. These are shown for each ROI, along with their 95% confidence intervals (CIs), in Figures 1 and 2. Averaged across all ROIs, the lowest RC achieved using two FAs was with 2.5° and 20°, with a value of 535 (358, 1056) ms compared to 553 (370, 1089) ms using all eight FAs. From Figures 1 and 2, it can be observed that for subcutaneous fat, bone marrow, and Liver, fitting with any FA pair with a lower FA of 7.5° or below has a comparable reproducibility to fitting with all eight FAs. The same is true for the paravertebral muscle and spleen using a lower FA of 2.5° or 5.0°. This is indicated by the RC CIs for the fitting with these FA pairs overlapping with that of the fitting with eight FAs.

The RDC was calculated for fittings using two FAs compared to fitting using all eight FAs. These are shown for each ROI in Figures 3 and 4. Across all ROIs, the best reproductivity was achieved using the FA pair of 2.5° and 20°, with an RDC of 392 (256, 528) ms. Figures 3 and 4 show that for all ROIs, reproducibility is best when using a lower FA of 2.5° or 5.0°.

Conclusion

WB T1 mapping can be achieved within a clinically viable time with the use of VFA by acquiring only two FAs with minimal loss to precision, providing the lower FA is between 2.5° and 7.5°. This could enable its use as a quantitative imaging biomarker in metastatic cancer. From this empirical study, we recommend an FA pair of 2.5° and 20°.

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Figures

Tissue	Present Study: T1 Relaxation Time (ms)*	Present Study: ROI volume (mm³)*	Present Study: No. of Subjects (scans per subject)	de Bazelaire et. al 2004[19]: T1 Relaxation Time (ms)*	de Bazelaire et. al 2004[19]: ROI volume (mm³)*	de Bazelaire et. al 2004[19]: No. of Subjects (scans per subject)
Subcutaneous fat	394 ± 31	3086 ± 788	8 (3)	382 ± 13	797 ± 155	6 (1)
Bone marrow (L4 vertebra)	767 ± 140	755 ± 16	8 (3)	586 ± 73	1183 ± 343	6 (1)
Liver	1667 ± 181	2922 ± 0	8 (3)	809 ± 71	3133 ± 1030	6 (1)
Paravertebral muscle	1117 ± 137	3073 ± 0	8 (3)	898 ± 33	2436 ± 1030	6 (1)
Spleen	1854 ± 364	2200 ± 657	8 (3)	1328 ± 31	4274 ± 1251	6 (1)

* Data are mean ± SD

Table 1: Summary statistics from the ROIs in this study are given along with another study for comparison. For each tissue, the T1 value from our study is the mean of the mean ROI values from maps estimated via LLS fitting with eight FAs across all scans 28 scans (8 subjects, 3 rest-retests each). De Bazelaire et. al[19] measured T1 via inversion-recovery for single slices. Each of the six subjects was scanned once.

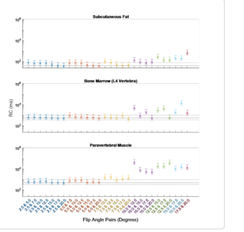

Figure 1: Graphs showing the RCs of LLS fitting using all 28 combinations of paired FAs, along with their 95% confidence intervals, for subcutaneous fat, bone marrow (L4 vertebra), and paravertebral muscle. The solid black line indicates the RC for LLS fitting using all eight FAs for comparison, and the dashed black lines are its 95% confidence interval.

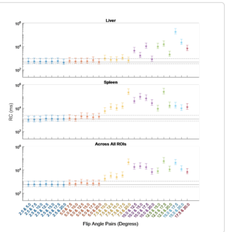

Figure 2: Graphs showing the RCs of LLS fitting using all 28 combinations of paired FAs, along with their 95% confidence intervals, for the liver, spleen, and across all five ROIs. The solid black line indicates the RC for LLS fitting using all eight FAs for comparison, and the dashed black lines are its 95% confidence interval.

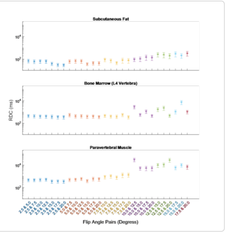

Figure 3: Graphs showing the RDCs of LLS fitting using two FAs compared to using eight FAs for all 28 combinations of FA pairs, along with their 95% confidence intervals, for subcutaneous fat, bone marrow (L4 vertebra), and paravertebral muscle.

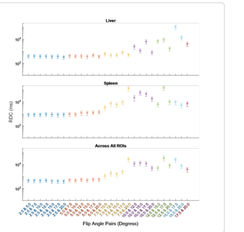

Figure 4: Graphs showing the RDCs of LLS fitting using two FAs compared to using eight FAs for all 28 combinations of FA pairs, along with their 95% confidence intervals, for the liver, spleen, and across all five ROIs.