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Evaluation of different approaches to plan radiotherapy with MRI-based proton density quantification

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Introduction

The treatment adaptation to each patient has led to the consideration of using magnetic resonance imaging for radiotherapy (RT) planning, due to its capacity to produce high-contrasted images, a better organ at risk (OAR) delineation and quantitative information on the tissues. The main difficulty is the indirect link between MRI and electronic density maps, which are necessary for dose calculation.

To overcome this difficulty, two approaches allow to build a synthetic CT: statistical methods based on bulk density assignment¹, atlas registration², or deep learning³; physical methods based on quantitative MRI such as proton density (PD) quantification⁴.

Studies^{4,5} show that the electronic density can be linked to the hydrogen content of the tissues: its mass stopping power and mass attenuation coefficients are more significant than the other atoms between 0.2 and 8 MeV⁴, the knowledge of the hydrogen content of the tissues could be a solution for RT planification. PD is a physical property which can be accessible with specific MRI sequences.

We focus on head and neck tumors, which require a large field of view in the coronal plane, about 500mm from the top of the head to the upper part of the humerus. This area has not been clinically validated, unlike brain and pelvis. The numerous OARs (brainstem, optics nerves...) make it a challenging area.

This paper describes a preliminary study on a PD quantification method for head and neck cancers.

Methods

From the magnetization at the origin M_0 , PD can be measured with the following equation: $M_0(x, y, z) = G(x, y, z) \circ PD(x, y, z)$, with G the coils sensitivity maps.

First, we have constituted a phantom with different concentrations of D2O (ranging from 0 to 80%) in H2O saline solution mimicking different proton concentrations to measure the relationship between theoretical and experimental PD, see Figure 1, the other tubes are filled with fat. Second, a 3D Spiral VIBE UTE sequence acquired on a Siemens 3T Vida (Siemens Healthineers, Germany), with an ultra-short echo time (30 μ s) has been used to reach M_0 . This sequence has a TR of 3.12 ms and a flip angle of 5°. The echo time is short enough to assume that $S(UTE) \sim M_0$.

To retrieve the coils sensitivity maps, we evaluated different algorithms: SENSE⁷, ESPIRIT⁸ and adaptive reconstruction (AR)⁹. Tests on the phantom were performed with different coils setups: Head and neck only, Body only and lower part of Head and neck + Body, which is the configuration we want to use for a protocol on patients with a contention mask. Linear regressions were computed between the tube's intensities

corrected from coils sensitivities and the theoretical value of PD. On-line coil sensitivity correction methods available on our MR system, “Prescan” and “B1-filter”, were also evaluated to directly estimate. The phantom was also scanned in the CT scanner for different energies.

Results

The linear determination coefficients of the regressions with the different filters and for the CT images are presented in Figure 2. Examples of regressions are given Figure 3.

With a 32 Go RAM, INTEL I7, 2.50 GHz processor personal computer, the computation time for SENSE algorithm was 1 min, 13 min 20 s for ESPIRiT and 2 min for AR.

Discussion

Results show that the spiral VIBE UTE sequence allows to obtain a linear relationship between theoretical PD and MRI signal which is, as expected, better after coil sensitivity correction. The three algorithms used to estimate coils sensitivities provide satisfying results, the MRI filters give even better results. The Head and neck coil only configuration gives the best results, as expected. The results for the coil configuration of the protocol are a bit worse but still satisfying. The results of the CT images confirm that there is a relationship between PD content and the Hounsfield Unit values of the CT, which are linked to the electronic density.

Conclusion

Our work demonstrated that MRI could be used for PD quantification in head and neck region, and that PD can be linked to the Hounsfield Unit.

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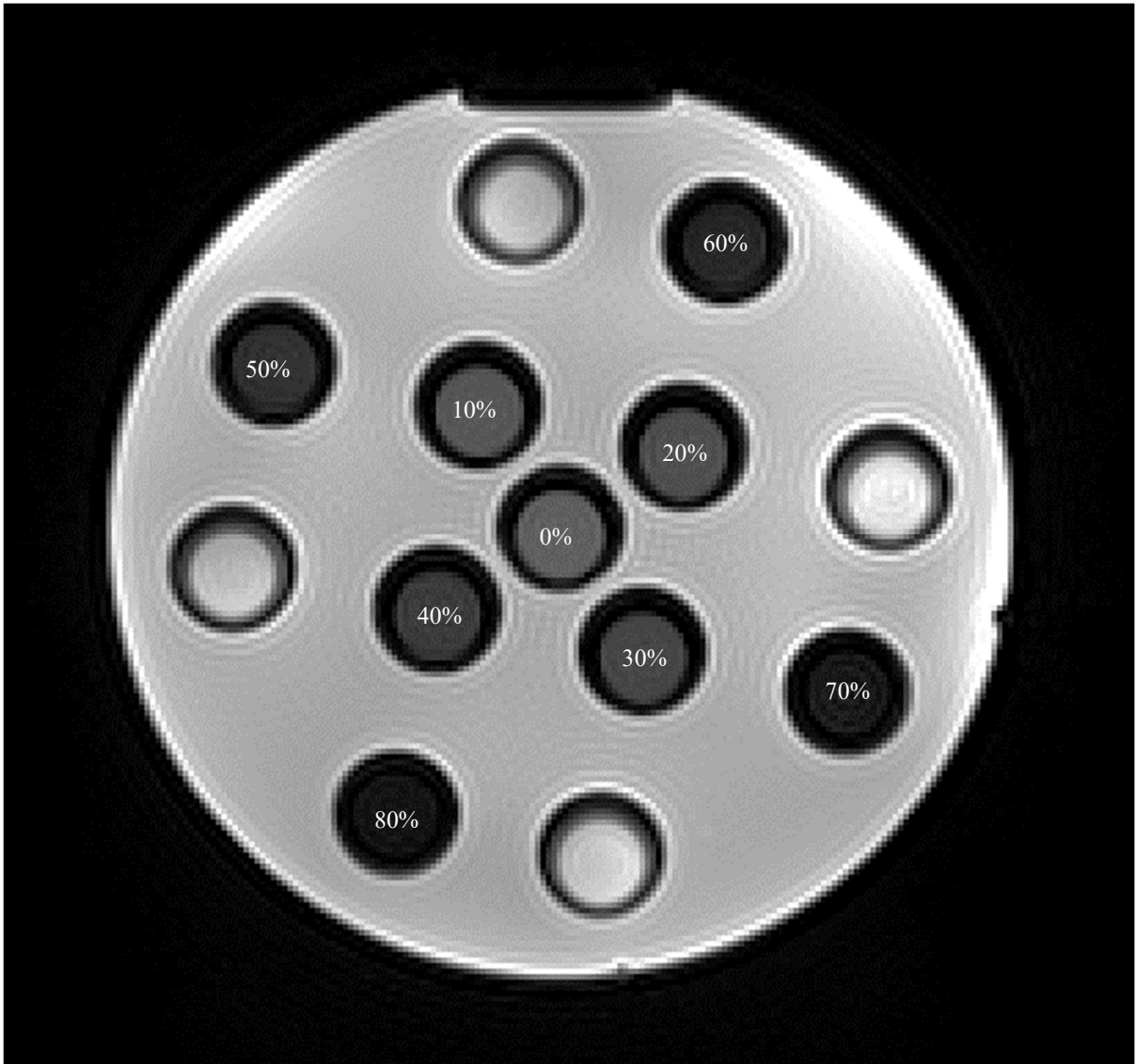


Fig. 1: Phantom concentrations of D_2O , the percentage is written on the tubes, completed with volumes of H_2O in order to measure the relationship between theoretical and experimental proton densities

R ²	Raw image	SENSE	RA	ESPIRIT	B1 faible	B1 moyen	B1 élevé	Prescan modéré	Prescan normal	Prescan large bande
Head	90,9	94,2	93,6	91,9	97,9	97,5	94,5	98,3	98,9	98,9
Body	66,9	66,0	63,9	27,0	97,3	97,0	93,6	93,7	97,2	97,3
Head lower part + body	87,2	90,2	90,6	82,8	98,6	98,4	96,1	96,7	98,8	98,5
R ²	40 keV	45 keV	50 keV	55 keV	70 keV	100 keV	120 keV	140 keV		
CT	83,3	84,6	85,5	86,2	87,0	90,4	94,7	87,7		

Fig. 2: Linear determination coefficients of the linear regressions with the different filters and for the CT images

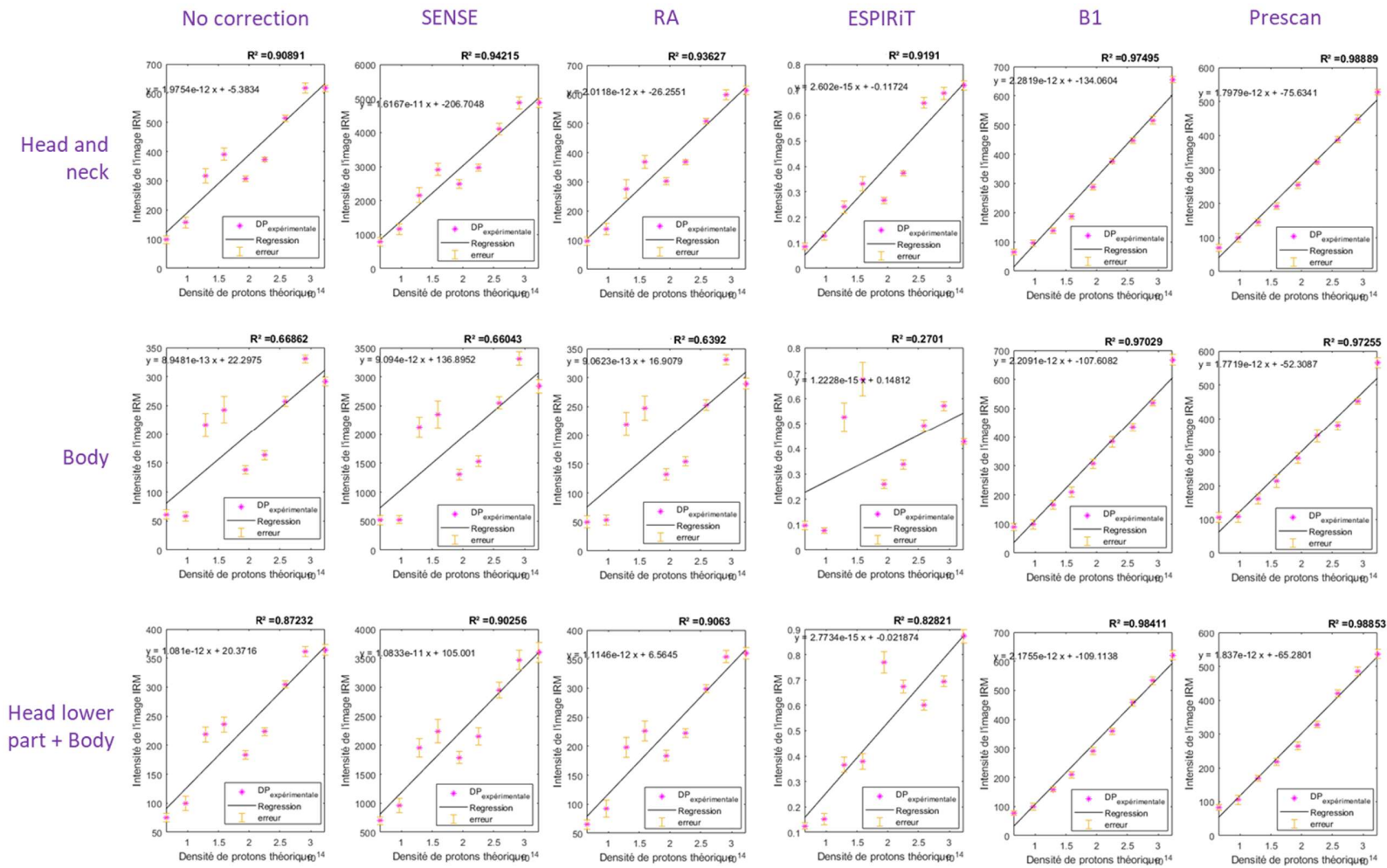


Fig. 3: Example of linear regression for several algorithms