Quantitative Assessment of Restriction Spectrum Imaging Using a Diffusion MRI Phantom

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INTRODUCTION

- Restriction Spectrum Imaging (RSI) is an advanced diffusion model that goes beyond the standard diffusion tensor to describe water molecule movement in tissues[1] (Fig. 1).

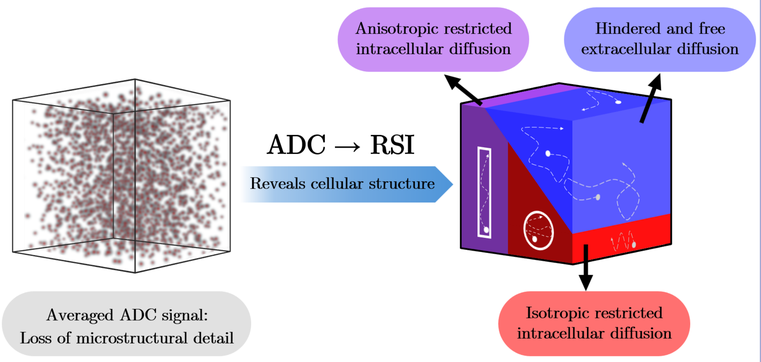

FIG. 1 – RSI can separate water signal coming from free water, hindered and restricted compartments, contrary to the ADC.

- Although RSI has demonstrated improved lesion conspicuity in vivo across multiple organs, its stability and reproducibility under controlled experimental conditions remain largely uncharacterized[2,3,4].

- This work evaluates the repeatability and quantitative behavior of RSI using a diffusion phantom with known diffusivities.

METHODS

- Images of a diffusion phantom (CaliberMRI, USA) were acquired on a 3.0 T scanner (MAGNETOM Prisma, Siemens Healthineers, Germany) over five consecutive days, with 3 repeated runs per day.

- Two head coils (20/64ch) were used, to assess hardware variability. Scanning parameters (Tab. 1) were the same with both configurations.

- RSI maps were compared against reference diffusivities (ADC) obtained from known polyvinylpyrrolidone concentrations (%PVP).

- Intra/inter-day repeatability and stability were quantified using the repeatability coefficient (RC) and coefficient of variation (CV), defined as follows:

$$RC = 2.77 \times \sigma \qquad CV = \frac{\sigma}{\bar{x}} \times 100$$

Tab. 1 – Acquisition parameters of the DWI sequence and the structural reference scan.

Sequence	T1w MPRAGE	DWI
TE/TR/TI (ms)	2.46/2200/900	104.8/3830/-
FoV (mm)	230 x 230	220 x 220
Matrix size (resolution)	256 x 256 (0.9 x 0.9 x 0.9)	128 x 128 (1.7 x 1.7 x 1.7)
TA (min:ss)	5:07	4:05
b-values (# vol)	-	0/500/1500/4000/8000 (7/6/6/15/15)

RESULTS & DISCUSSION

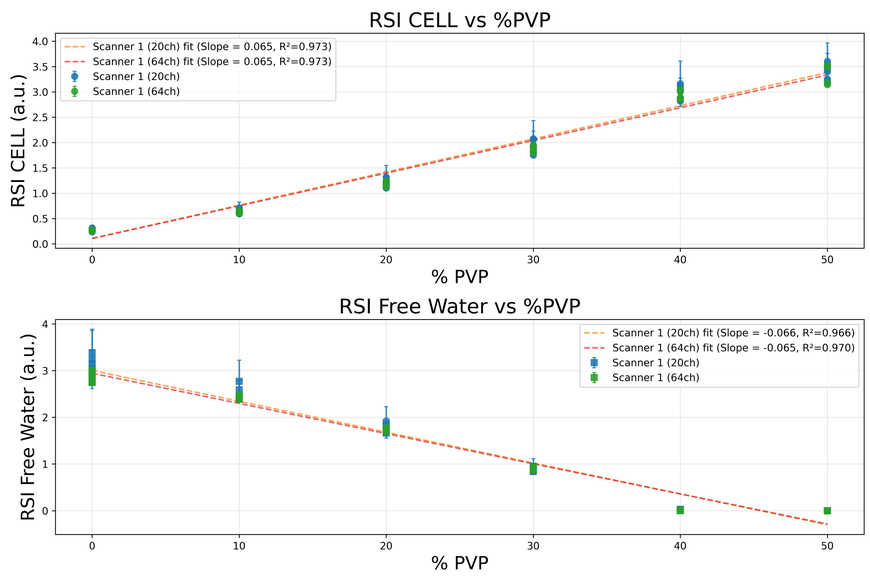

FIG. 2 - Relationship between RSI cellularity (CELL, top) and Free Water fraction (bottom) signal map and %PVP. Data points are the daily mean computed from repeated measurements for each vial, with error bars showing the standard deviation. Dashed line represents the linear fit for each coil tested.

- RSI CELL maps showed a strong linear relationship (Fig. 2) with higher %PVP for each coil configuration tested (20ch: slope=0.066, R^2=0.973, 64ch: slope=0.065, R^2=0.973).

- Free water signal map showed the inverse relationship with increasing %PVP concentration (Fig. 2) (20ch: slope=-0.066, R^2=0.966, 64ch: slope=-0.065, R^2=0.970).

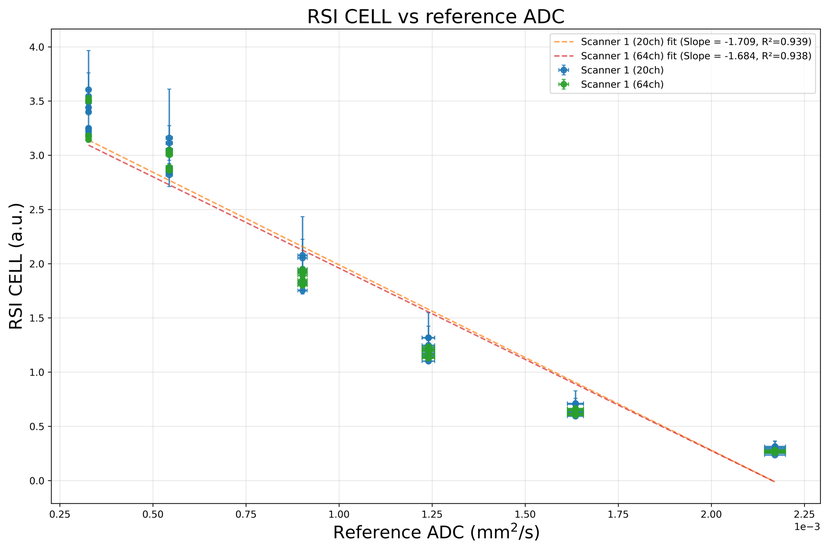

FIG. 3 – Comparison between RSI CELL map signal intensity and reference apparent diffusion coefficient (ADC) from known diffusivities inside the DWI phantom.

- RSI CELL maps obtained from both coil configuration decays monotonically with increasing ADC values (Fig. 3).

- For both maps, the 20ch head coil underperformed in comparison to the 64ch head coil, resulting in higher CV for intra- and inter-day measurements (Fig. 4). This was observed as well for RC for both coil (Fig. 5).

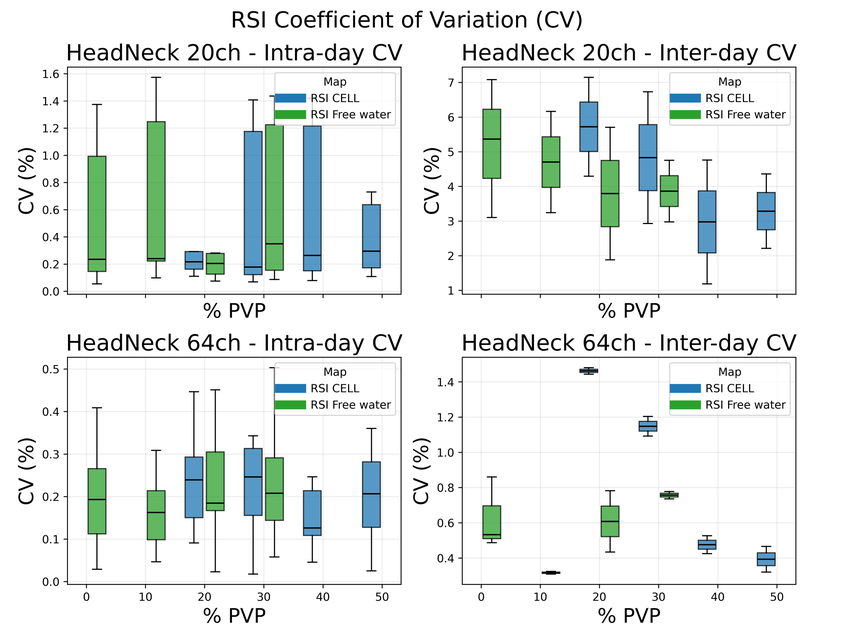

FIG. 4 – Coefficient of variation (CV) obtained for each coil configuration tested across the different %PVP. RSI CELL CV is displayed for %PVP above 10%, and RSI Free Water for %PVP lower than 40%.

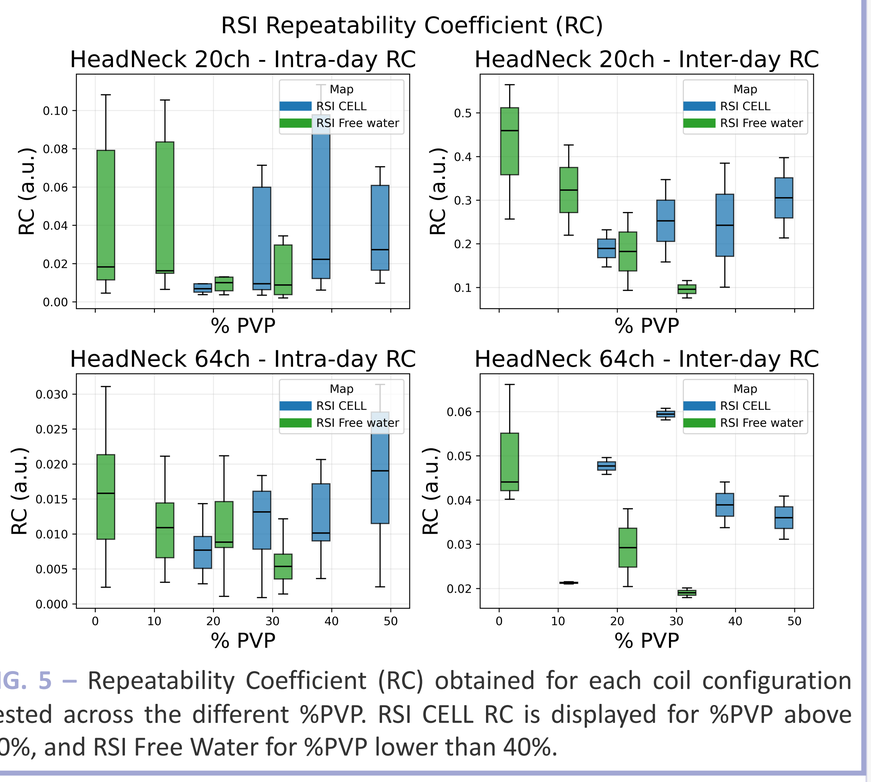

FIG. 5 – Repeatability Coefficient (RC) obtained for each coil configuration tested across the different %PVP. RSI CELL RC is displayed for %PVP above 10%, and RSI Free Water for %PVP lower than 40%.

CONCLUSIONS

- RSI CELL and Free Water fraction maps showed a linear relationship between signal intensity and %PVP.

- RSI maps showed reliable results, especially for the 64ch head coil, both for intra and inter-day.

- Further validation of the impact on acquisition parameters, such as b-values used are needed to assess the impact on RSI maps.

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