Variable Flip Angle Pipeline
for in vivo ^{23}Na Concentration Measurements

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Context

Sodium (^{23}Na) is the second most concentrated NMR sensitive nuclei in the human body and is involved in cellular homeostasis. Therefore, studying its distribution in human tissues can provide insights about cellular viability. Here, we applied a variable flip angle (VFA), approach[1] to simultaneously obtain [Na], T_1 maps, and high SNR sodium images, in vivo, in clinically feasible times.

Theory

Two steady-state Gradient Recalled Echo sequence acquired with the Variable Flip Angle method allow to estimate M_0 and T_1 by solving a linear system of equations:

$$\frac{S}{sin(B_1^+\alpha)} = a\,\frac{S}{tan(B_1^+\alpha)} + b$$

Leading to :

$$T_1 = -\frac{TR}{\ln(a)} \ and\ kM_0 = -\frac{b}{(1-a)e^{-\frac{TE}{T_2^*}}}$$

Optimization were made to determine minimal TR to get sufficient SNR under SAR limitations

The Double Angle Method (DAM[2]) is used to compute a B_1^+ map

$$B_1^+ = arccos\left(\left|\frac{I_{2\alpha}}{2I_\alpha}\right|\right)$$

Reciprocity principle enables to obtain reception profile B_1^-
Finally Spin density is assessed :

$$\rho = k\,\frac{M_0}{B_1^-}$$

In vivo concentration model in brain tissue[3,4]

$$TSC = ICC \times IVF + ECC \ \times (1 - IVF) \ \in \ [36,39] mmol.L^{-1}$$

Material and Methods

4 healthy patients were recruited and were scanned on a 3T scanner (Siemens PRISMA) after providing written consent. A double resonant ^{1}H/^{23}Na coil (Rapid Biomedical) was used for imaging.

Acquisitions were performed using the FLORET[5] sequence with a chosen TR/TE=20/0.1ms at FA of 25°/55° with TA of 9 minutes each.

Comparison to state of the art density weighted TSC acquisition with parameters TR/TE=120/0.1ms with FA=90° and TA of 18 minutes.

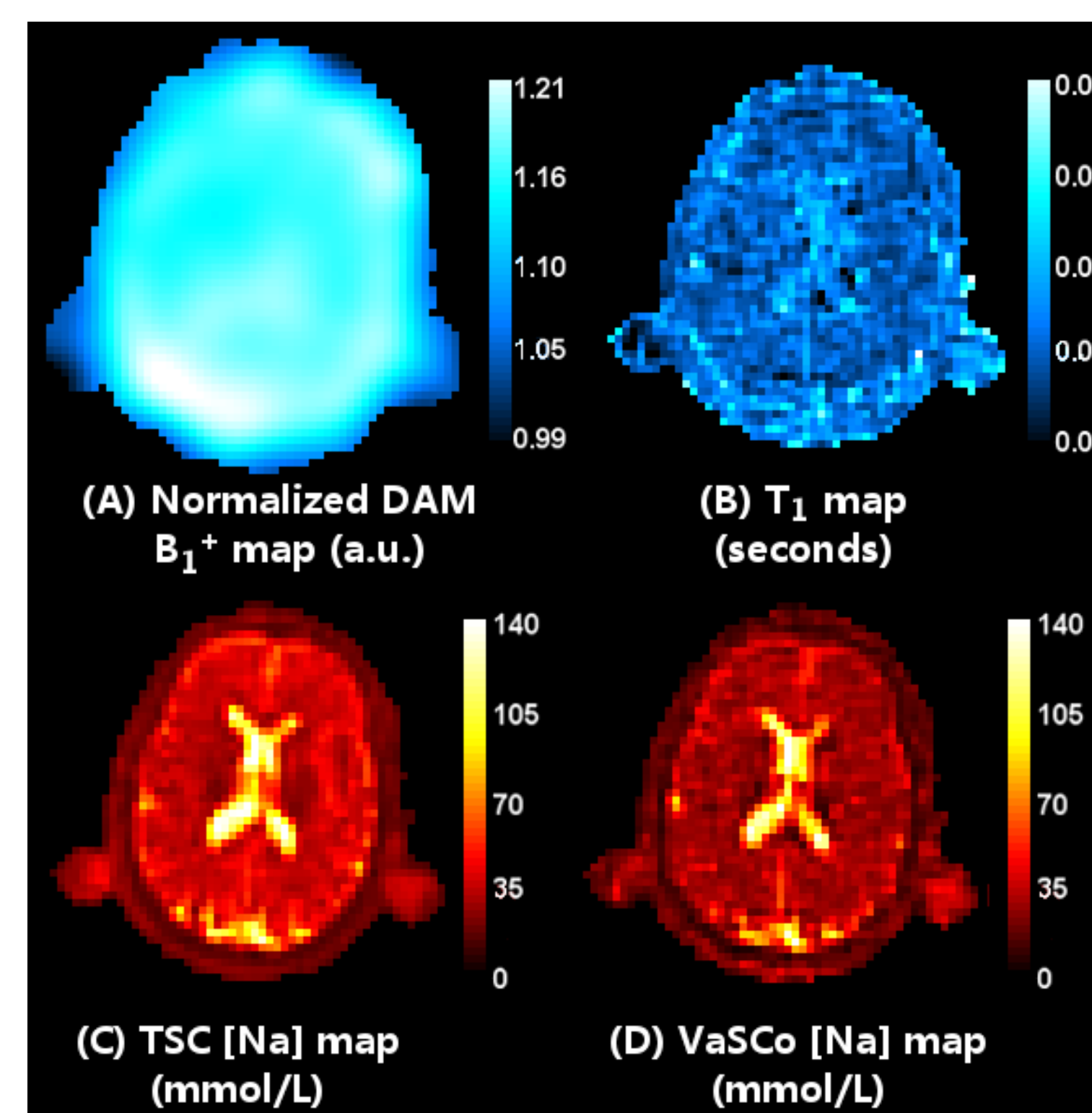Image resolution was 4mm isotropic on a 256mm isotropic FOV.

Acquisitions were fragmented to account and correct possible motion.

Images were reconstructed using the NUFFT[6] algorithm and processed using the ANTs[7] package for R[8] and homemade python functions.

VFA and TSC images were corrected for saturation effects[9] and coil profiles prior to affine Intensity calibration using external concentration references
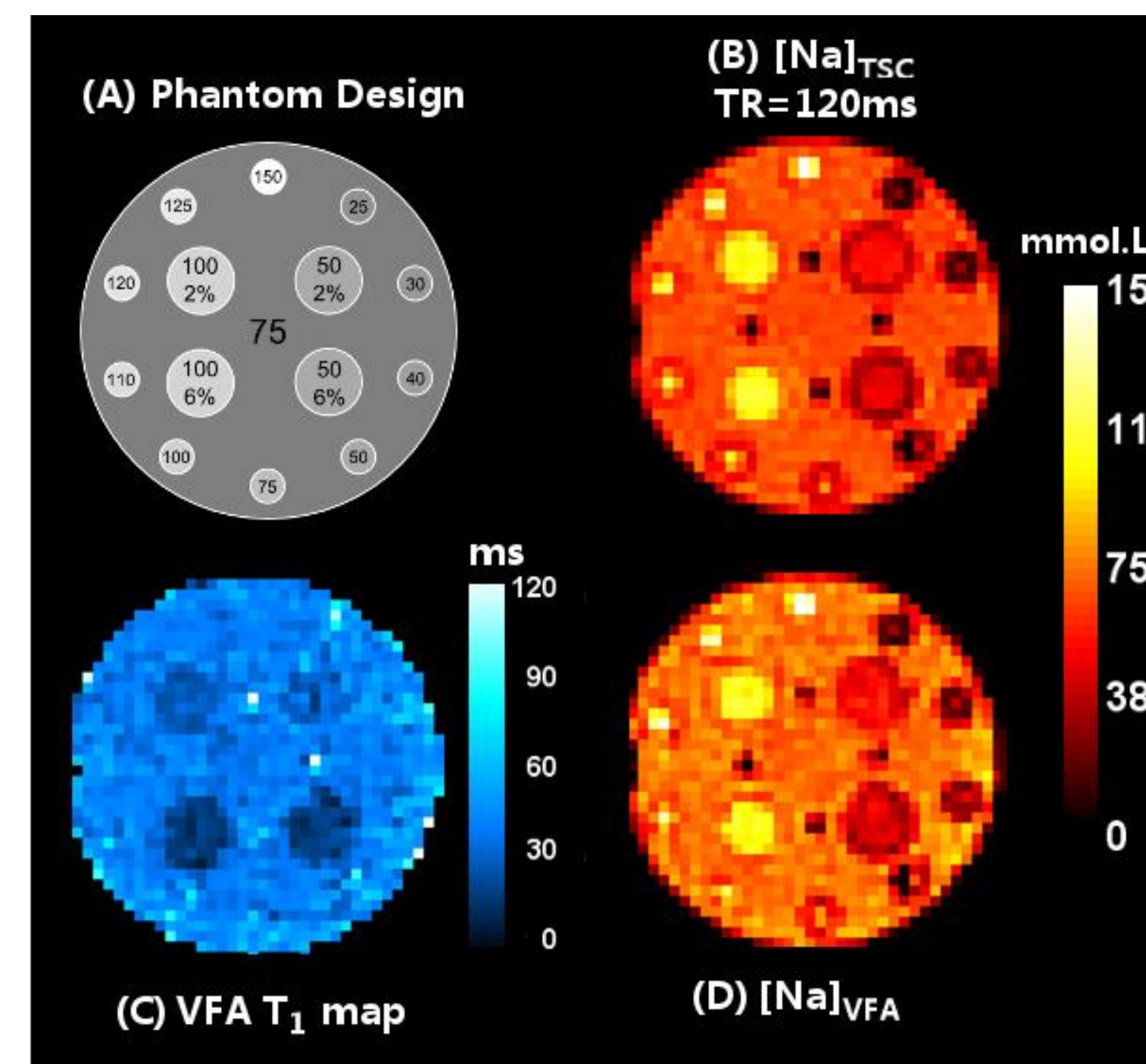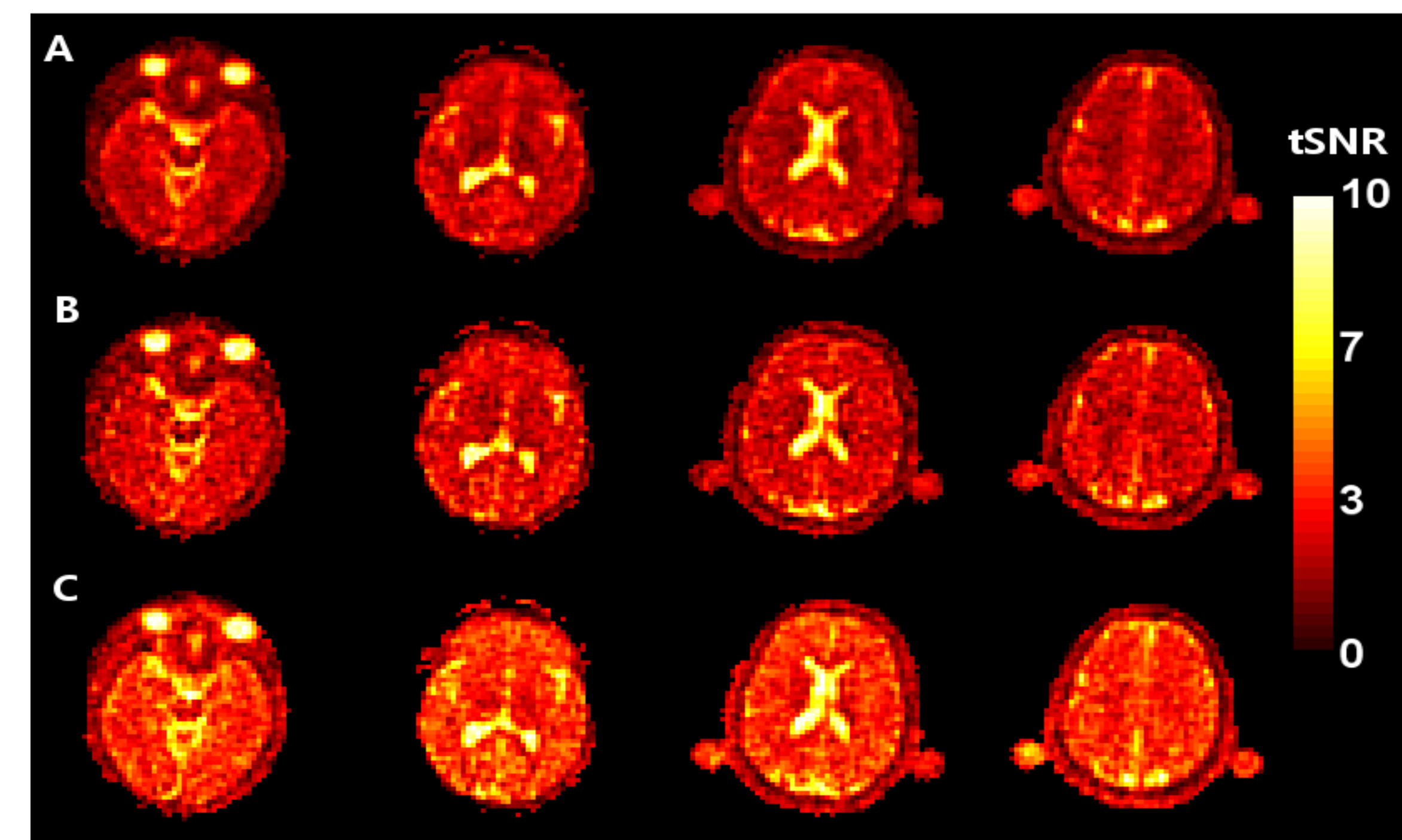
Results

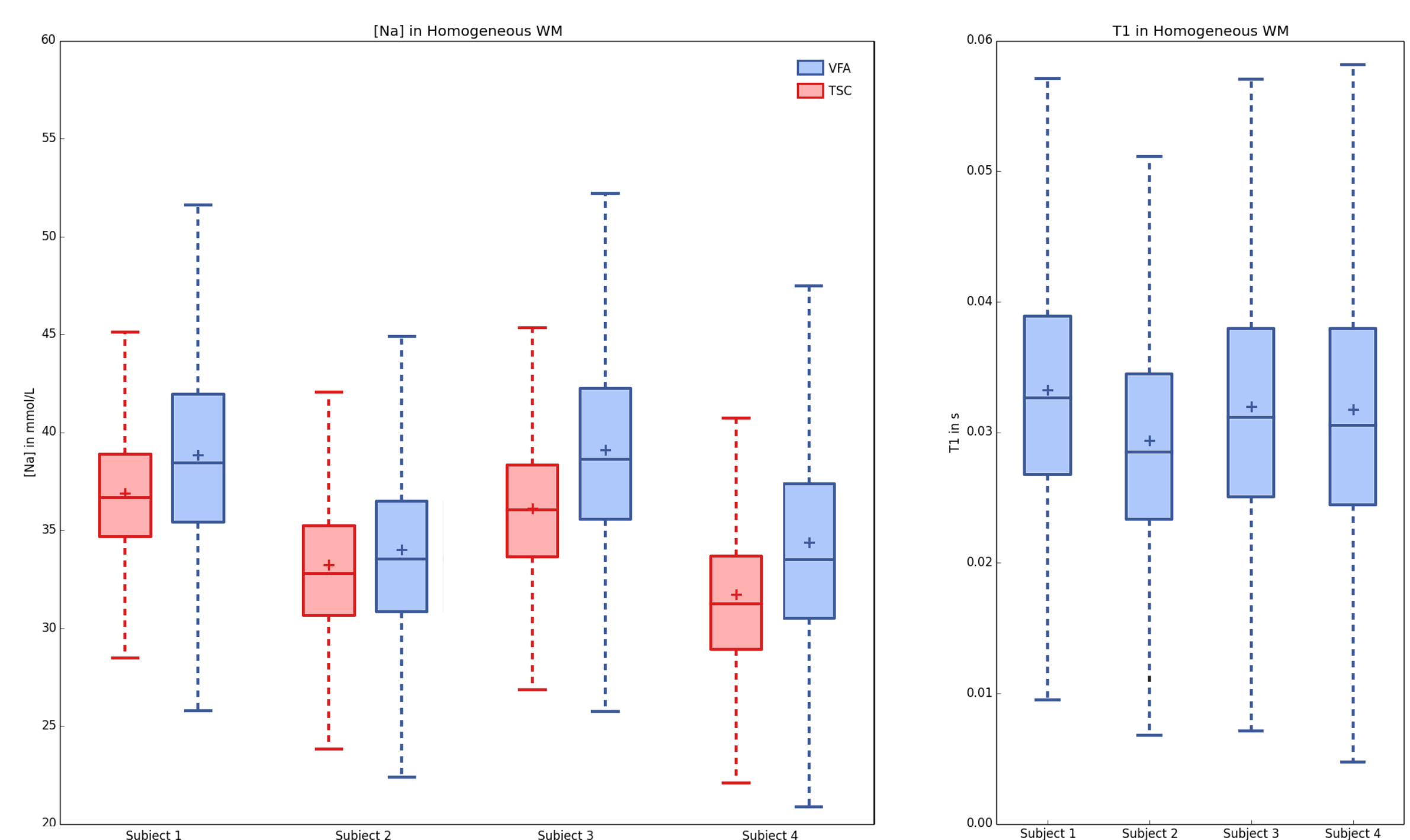Phantom Design (A) TSC map (B) VFA T_1 map (C) and associated Concentration map (D)

Time normalized SNR comparing the Spin Density weighted TSC Image (A) with the T_1 weighted Image with FA=25° (B) and FA=55° (C)

In vivo results showing the B_1^+ spatial distribution (A), the computed T1 map, the TSC [Na] and the VFA [Na] maps (C,D)

Boxplot showing distribution of Concentration and T_1 values, in a large homogeneous White Matter ROI for our 4 volunteers allowing to compare the two methods

Perspectives

Our method enables to account for most sources of acquisition bias such as B_1^+, B_1^- and robustly extract both concentration and T_1 values in agreement with literature. The use of T_{1W} acquisition offers a better time sampling efficiency compared to state of the art spin density weighted acquisition. T_1 extraction induces a larger variance in concentration images but enables a better account for possible tissues changes brought by pathologies. As most interesting variations occur in the intracellular compartment we aim at adding to our method a multi echo approach[10] to probe intracellular sodium content.

References

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