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

Arthur Coste¹, Fawzi Boumezbeur¹, Alexandre Vignaud², Guillaume Madelin², Kathrin Reetz³, Denis Le Bihan¹, Cécile Rabrait-Lermain¹ and Sandro Romanzetti³

¹ NeuroSpin, ISVFI, DRF, CEA, Université Paris Saclay, Gif-sur-Yvette, France
² Center for Biomedical Imaging, Department of Radiology, New York University Langone Medical Center, New York, USA
³ Aachen University Clinic, Neurology Department, Aachen, Germany

**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 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:

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

Leading to:

$$T_1 = \frac{TR}{\ln(a)} \quad \text{and} \quad kM_0 = -\frac{b}{(1-a)e^{\frac{TR}{2a}}}$$

Optimization were made to determine minimal TR to get sufficient SNR under SAR limitations. The Double Angle Method (DAM) is used to compute a $B_1^*$ map

$$B_1^* = \arccos\left(\frac{|2a|}{2a}\right)$$

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:

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

**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 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 algorithm and processed using the ANTs package for R and homemade python functions.

VFA and TSC images were corrected for saturation effects and coil profiles prior to affine intensity calibration using external concentration references.

**Results**

In vivo results showing the $B_1^*$ spatial distribution (A), the computed $T_1$ map, the TSC [Na] and the VFA [Na] maps (C,D)

**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 to probe intracellular sodium content.

**References**