In Vivo Sodium MRI: Biomedical Applications

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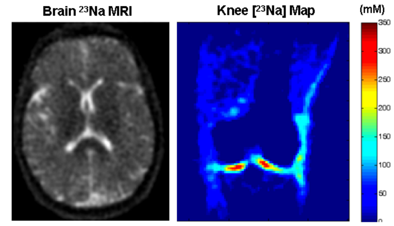
PURPOSE:



Thanks to technological developments during the last 20 years, sodium (^{23}Na) MRI is nowadays a field of research in great expansion. Its application to in vivo medical imaging directly gives biochemical/metabolic information on number of human diseases that complement the conventional morphological imaging methods. The purpose of this presentation is to give an overview of in vivo sodium MRI, describe its state of the art, its biomedical applications, technological challenges and future prospects.

OUTLINE OF CONTENT:

1. Why Sodium MRI?
- **1.1 Biochemical information**
  - Cellular function, osmotic balance, solute transport, synaptic transmission, non-invasive technique
- **1.2 History of Sodium MRI**
  - 1st Sodium MRI in the 80's, technological improvements, high fields (3T, 7T, 9.4T), new RF coils

2. Sodium Magnetic Resonance
- **2.1 Sodium Magnetic Properties**
  - Spin 3/2, quadrupolar moment, interaction with electric field gradients, low sensitivity in vivo
- **2.2 Quadrupolar Relaxation**
  - Residual quadrupolar coupling, slow motion, biexponential T1 and T2 Relaxation
- **2.3 Multiple Quantum Filters**
  - Double and Triple Quantum Filters (DQF and TQF), intra and extracellular sodium

3. In Vivo Sodium Imaging
- **3.1 Sequences**
  - UTE, 3D GRE, 3D Radial, Density Adapted 3D Radial, TPI, 3D Cones, SPRITE, SWIFT
- **3.2 Sodium Concentration Maps**
  - Calibration phantoms, linear regression, relaxation correction
- **3.3 Fluid and Extracellular Sodium Suppression**
  - Inversion recovery, shift reagent, DQF, TQF

4. Biomedical Applications
- **4.1 Neurology**
  - Brain: Tumors, strokes, MS, Alzheimer's disease, cell viability and homeostasis, ischemia, intracellular sodium
- **4.2 Musculoskeletal (MSK)**
  - Knee, Hip, Wrist, Ankle: Osteoarthritis, cartilage degeneration, proteoglycans and fixed charge density (FCD)
  - Skeletal Muscle: Diabetes, myotonic dystrophy, intracellular sodium
- **4.3 Cardiac**
  - Heart: Cell viability and homeostasis, ischemia, intracellular sodium
- **4.4 Body**
  - Breast: Tumors, intracellular sodium
  - Kidney: Sodium gradient, extracellular sodium regulation
  - Spine: Intervetebral disc, proteoglycans and fixed charge density
- **4.5 Therapeutic response**
  - Chemotherapeutic resistance/monitoring, intracellular sodium

5. Limitations and Perspectives
- **5.1 Physical and biological limitations**
  - Low NMR sensitivity in vivo (low concentration, low gyromagnetic ratio), intra- and extracellular content, low SNR, SAR
- **5.2 Technological limitations**
  - Need of high and ultra high field systems, B0 and B1 field inhomogeneity, RF coils sensitivity, preamplifiers, sequence programming, image reconstruction
- **5.4 Perspectives**
  - Multichannel double tuned RF coils, optimal control theory to design RF pulses for fluid or extracellular sodium suppression, new image reconstruction methods

SUMMARY:

In this overview, we present in the 1st section why sodium MRI can be clinically interesting as it directly gives biochemical/metabolic information non-invasively, we also describe its short history since the early 80's and the significant improvements of this method due to technological developments in the 90's (high magnetic fields, UTE sequences, non-cartesian reconstruction methods, RF coils, electronics). The 2nd section describes the magnetic properties of the sodium ion $^{23}Na^+$ in vivo: it's a spin 3/2 nucleus with a quadrupolar moment that strongly interacts with the surroundings via the electric field gradients, leading in general to a biexponential T1 and T2 (T2short~1ms, T2long~15ms) in biological tissues. Multiple quantum filters can be implemented on the clinical MRI scanners and allow us to discriminate between sodium nuclei with slow motion and fast motion (in the intra or extracellular compartments). The 3rd section describes the ultrashort TE sequences that have been developed in order to improve the signal-to-noise ratio and resolution of the images and thus reduce the time of acquisition of the data. Methods to quantify the sodium concentration using calibration phantoms and to suppress fluid signals are also presented. The 4th section reviews the main biomedical domains where sodium MRI has been applied so far: neurology (brain tumors, strokes, MS, Alzheimer's), MSK (cartilage degeneration in osteoarthritis), cardiac (cell viability in the heart), body (breast tumors, sodium gradient in kidney, proteoglycans in intervertebral disc), chemotherapeutic response. In the 5th section the limitations of sodium MRI are described (low SNR and low resolution images with long times of acquisition, the need of high fields with good homogeneity) as well as some perspectives on overcoming these problems, such as using multichannel RF coils and creating new acquisition and reconstruction methods.