Introduction

Chloride (Cl\textsuperscript{-}) is the most abundant anion in the mammal organism playing an important role in many cellular processes. For instance, plasma membrane Cl\textsuperscript{-} currents are important for the regulation of excitability in nerve and muscle. Moreover, Cl\textsuperscript{-} ions play a crucial role in controlling the ionic composition of the cytoplasm and the volume of cells [1]. In order to investigate the feasibility of combined in vivo \textsuperscript{35}Cl, \textsuperscript{23}Na and \textsuperscript{1}H MRI we developed a rf coil setup to measure \textsuperscript{35}Cl, \textsuperscript{23}Na and \textsuperscript{1}H signals in one scanning session without moving the subject or changing the setup.

Material and Methods

For the \textsuperscript{1}H and \textsuperscript{23}Na measurements we used a linear double tuned volume resonator with an inner diameter of 7 cm from Bruker (Ettlingen, Germany). Additionally, we placed a surface coil on the head of the animal that operated at the resonance frequency of \textsuperscript{35}Cl at 9.4 T of 39.2 MHz. This coil was constructed from silver wire with 3 mm diameter. A single loop of 35 mm diameter was bent on a 35 mm plexiglass half cylinder to achieve an optimal filling factor for a rat head. The \textsuperscript{35}Cl coil was built large enough to cover the whole brain for sure and is glued to the plexiglass half cylinder to which it was bent.

Proton imaging was performed using a multi slice multi echo (MSME) sequence with TR = 2000 ms, TE\textsubscript{1} = 13 ms and TE\textsubscript{2} = 65 ms (two images per slice). The field of view (FOV) was 64 × 64 mm\textsuperscript{2} at a matrix of 256 × 256 with 9 coronal slices of 3 mm thickness and an inter-slice distance of 3.5 mm. The total measurement time (TA) was 6 min 24 sec.

The \textsuperscript{23}Na and \textsuperscript{35}Cl imaging was done using a slice selective ultra short echo time (UTE) pulse sequence with radial k-space acquisition [2]. For both nuclei 3 coronal slices with FOV = 64 × 64 mm\textsuperscript{2}, matrix of 64 × 64, slice thickness = 3 mm and an inter-slice distance of 3.5 mm were measured. The positions of the 3 slices were matched with the slice positions of the corresponding \textsuperscript{1}H images by means of the scanner software Paravision\textsuperscript{®} 5. The parameters for the \textsuperscript{23}Na imaging were TR = 40 ms, TE = 0.321 ms, readout bandwidth = 25 kHz/FOV, number of averages = 225 and TA = 30 min 17 sec. For the \textsuperscript{35}Cl imaging the following parameters were used: TR = 40 ms, TE = 0.448 ms, readout bandwidth = 25 kHz/FOV, number of averages = 455 and TA = 1 h 1 min.

Results and Discussion

Multinuclear MRI of \textsuperscript{35}Cl, \textsuperscript{23}Na and \textsuperscript{1}H was applied on the head of a healthy rat and on a rat displaying a focal cerebral infarction in the right hemisphere of the brain. Columns a-e show the results of the in vivo MRI on a healthy rat whereas columns f-j show the results measured on a rat displaying a focal cerebral infarction. In the \textsuperscript{T2} weighted \textsuperscript{1}H images the area of infarction can be identified by the brighter areas in the right hemisphere of the brain due to ischemic swelling. Similar behaviour is observed in the \textsuperscript{23}Na and \textsuperscript{35}Cl images. Compared to the healthy tissue, a signal enhancement of a factor of 2.9 (\textsuperscript{23}Na) and of 2.2 (\textsuperscript{35}Cl) is observed in the area of infraction. The increase in signal is attributed to an increase in concentration of sodium and chloride ions. Note, the \textsuperscript{35}Cl images were measured with a surface coil therefore mainly the brain of the rat is visible in the corresponding images (column c + h).

The coil setup and the measurement parameters of the \textsuperscript{35}Cl and \textsuperscript{23}Na MRI were a compromise in order to achieve almost the same image quality (SNR and resolution). Despite the fact that the signal intensity of \textsuperscript{35}Cl is expected to be approx. 9.6 times lower than the signal intensity of \textsuperscript{23}Na, the \textsuperscript{35}Cl signal was sufficient to perform in vivo \textsuperscript{35}Cl MRI with acceptable image quality in a measurement time of 1h. The total measurement time for the multinuclear MRI was 2h. \textsuperscript{35}Cl MRI allows non-invasive in vivo studies on pathologies or physiological processes which result in a change of Cl\textsuperscript{-} concentrations. Since chloride and sodium ions are transported concurrently, combined in vivo \textsuperscript{35}Cl, \textsuperscript{23}Na and \textsuperscript{1}H MRI may provide a new approach to study diseases like stroke, ischemia or cystic fibrosis.

References: