High Definition Sodium (^{23}Na) In Vivo MRI of the Human Eye at 7.0 Tesla: Need for Substantially Enhanced Spatial Resolution than Commonly Used in Brain MRI

Daniel Wenz[1], Andre Kuehne[2], Till Huelnhagen[1], Armin M Nagel[3,4], Helmar Waiczies[2], Oliver Stachs[5], Erdmann Seeliger[6], Bert Flemming[6], Thoralf Niendorf[1,2]

[1]Berlin Ultrahigh Field Facility (B.U.F.F.), Max Delbrueck Center for Molecular Medicine in the Helmholtz Association, Berlin Germany, [2] MRI.TOOLS GmbH, Berlin, Germany. [3] Institute of Radiology, University Hospital Erlangen, Erlangen, Germany, [4]Division of Medical Physics in Radiology, German Cancer Research Centre (DKFZ), Heidelberg, Germany, [5]Department of Ophthalmology, University of Rostock, Rostock, Germany, [6] Institute of Physiology, Charité University Medicine, Berlin, Germany

Target audience: Imaging scientists, clinical scientists, radiologists and experts interested in ^{23}Na *in vivo* MRI of the human eye at 7.0 T.

Introduction

Primary active transport, which is carried out by Na^+/K^+-ATPase, is a crucial link in processes which occur in the human eye and its compartments: the formation of the aqueous humor, the maintenance of sodium/potassium gradient between the lens and the vitreous humor, the removal of water and lactic acid from the retina [1]. The goal of this study is to show why superior nominal spatial resolution (1.0 x 1.0 x 1.0) mm^3 is absolutely essential for ^{23}Na in vivo MRI of the human eye. Here we show in vivo sodium images of the human eye in order to benchmark the fidelity we obtained (1.0 x 1.0 x 1.0) mm^3 with the proposed approach against nominal spatial resolution (3.0 x 3.0 x 3.0) mm^3 which is typically used for ^{23}Na MRI of the human brain [2].

Methods

We used a six-channel transceiver array (Figure 1) which conforms very well to an average human head (Figure 1) [3]. Human imaging studies were conducted on a 7.0 Tesla whole-body system (Magnetom, Siemens, Erlangen, Germany) using 3D-DAPR imaging technique for ^{23}Na imaging and T_2-weighted RARE imaging technique for proton imaging. Proton MRI was feasible by incorporating a single-tuned volume coil (Siemens, Erlangen, Germany).

Results

We obtained sodium images from the eyes of two healthy, adult volunteers: one male (age = 53 years, BMI = 23.5 kg/m^2) and one female (age = 28 years, BMI = 25.1 kg/m^2) with nominal isotropic spatial resolution of (3.0 x 3.0 x 3.0) mm^3, (1.4 x 1.4 x 1.4) mm^3 and (1.0 x 1.0 x 1.0) mm^3 (Figure 2 and 3). We also achieved an isotropic spatial resolution of (1.0 x 1.0 x 1.0) mm^3 within 10:50 min scan time by reducing TR. Images acquired with an isotropic spatial resolution of 3 mm are depicted in Fig. 2 and 3 show a SNR which is superior to the high resolution data sets. Yet, all of the most important ocular compartments in the context of sodium physiology (vitreous humor, aqueous humor and lens) cannot be clearly delineated from the low resolution data. This shortcoming is resolved by using high spatial resolution ^{23}Na MRI of the eye as highlighted in Figure 2 and 3. This finding underscores the need and value of high definition (isotropic spatial resolutions: ≤1mm) for ^{23}Na in vivo MRI of the human eye.

Discussion and Conclusion

Sodium in vivo MRI of the human eye using our methodology provides millimeter isotropic spatial resolution images of excellent quality obtained within clinically acceptable scan times. Our data demonstrate that applying higher spatial resolution (1.0 x 1.0 x 1.0) mm^3 for ^{23}Na eye imaging at 7.0 Tesla, what is made feasible by using a six-channel transceiver array, clearly outperforms spatial resolutions currently used for brain imaging (3.0 x 3.0 x 3.0) mm^3 in terms of revealed detail. The size of an average eye and – particularly - its substructures has major impact on the imaging protocols which will be used in future patient studies. Unlike a spatial resolution of 3 mm isotropic, a spatial resolution of 1 mm isotropic enables the delineation of subtle structures of the eye as well as potential pathologies.

References

1. Kaufman PL, et al. Adler's Physiology of the Eye, 2011; 2. Nagel AM, et al., Invest Radiol, 2011; 3. Wenz D, et al., ISMRM 2017.

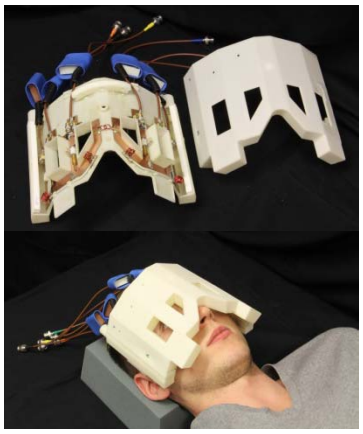

Figure 1: Top: the 6-channel transceiver array used in this study: copper loops soldered together with capacitors, inductors, cables and cable traps (wrapped with blue rubber). Bottom: the array placed on the face of an adult volunteer.

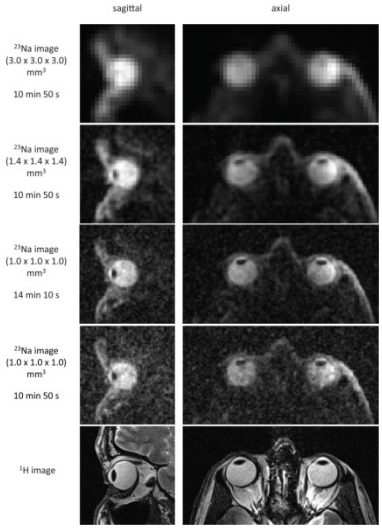

Figure 2: In vivo ^{23}Na image of the eyes of a healthy male volunteer (age = 53 years; BMI = 23.5 kg/m^2) obtained with an isotropic spatial resolution of 3 mm (top), 1.4 mm (middle) and 1.0 mm (bottom).

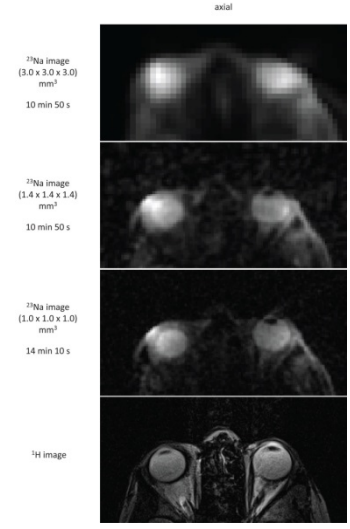

Figure 3: In vivo ^{23}Na image of the eyes of a healthy female volunteer (age = 28; BMI = 25.1 kg/m^2) obtained with an isotropic spatial resolution of 3 mm (top), 1.4 mm (middle) and 1.0 mm (bottom).