Biexponentially Weighted and Triple Quantum Filtered ^{35}Cl Imaging of the Human Brain

Alina Gilles[1], Nadia Benkhedah[1], and Armin M Nagel[1]
[1]*Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany*

PURPOSE

^{35}Cl is the most abundant anion in the human body and regulates many fundamental physiological processes. The concentration gradient over the cell membrane is highly regulated. Thus an alteration in the chloride homeostasis is an indicator for various pathological conditions, which involve epilepsy, brain edema, ischemia [1] and neurological inflammation [2]. ^{35}Cl is also involved in the migration of tumor cells within the brain [3] and a high intracellular chlorine concentration is associated with oncogenesis [4]. It has been shown that it is feasible to acquire triple-quantum filtered (TQF) ^{35}Cl images from the human brain to allow for a weighting towards intracellular chloride [5]. However, due to the low SNR only poor resolution images can be achieved. In this work, biexponentially weighted ^{35}Cl images have been generated as described in [6] and are compared to TQF ^{35}Cl images.

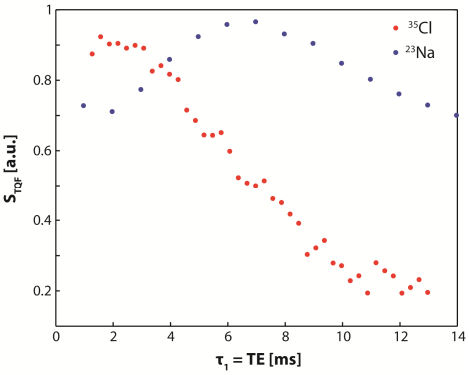

Fig.1: Spectral ^{35}Cl TQF data of the brain of a healthy volunteer as a function of preparation time and echo time.

METHODS

Pulse sequences were implemented on a 7-Tesla whole-body MR system (Magnetom 7 T, Siemens, Erlangen, Germany). A double-resonant (^{23}Na/^{35}Cl) birdcage coil (Rapid Biomed GmbH, Würzburg, Germany) was used for the measurements. For comparative purposes, ^{23}Na imaging experiments were performed.

A series of spectral TQF data was acquired before the imaging sequences to evaluate the optimum preparation time τ_1 and echo time *TE* by varying $\tau_1 = TE$.

Sequence parameters

^{23}Na MRI: *TE* = 0.35 ms, *TR* = 100 ms, T_{RO} = 10 ms, Δx^3 = (3 mm)^3, projections = 4000, averages = 1, T_A = 06:40 min.

^{35}Cl MRI (Fig.2/Fig.3): *TE* = 0.4 ms, *TR* = 85/140 ms, T_{RO} = 5 ms, Δx^3 = (6/11 mm)^3, projections = 8000/5000, averages = 1, T_A = 11:20/11:40 min.

^{35}Cl TQF (Fig.2/Fig.3): *TE* = τ_1 = 2 ms, τ_2 = 50 µs, *TR* = 140 ms, T_{RO} = 5 ms, Δx^3 = (15/11 mm)^3, projections = 5000, averages = 6, T_A = 70:00 min.

FOV is (21 cm)^3 and all images are interpolated to the same matrix size (180)^3.

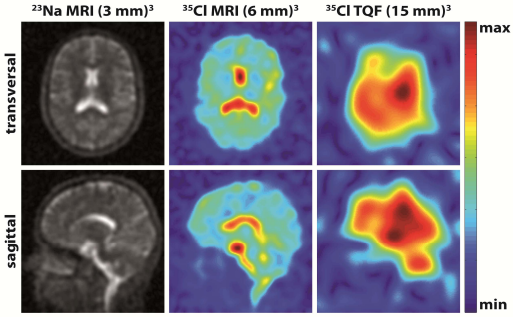

Fig.2: ^{23}Na, ^{35}Cl and ^{35}Cl TQF images of the brain of a healthy volunteer. Ventricles and brain parenchyma can be distinguished in ^{35}Cl images, but not in ^{35}Cl TQF images.

RESULTS & DISCUSSION

Spectral ^{35}Cl and ^{23}Na TQF data of the human brain (healthy volunteer, female, 25 years) as a function of $\tau_1 = TE$ are shown in Fig. 1. The maximum ^{35}Cl TQF signal intensity is reached around $\tau_1 = TE$ = 2 ms. This value is close to the value obtained from the calculation of the optimum preparation time using relaxation times reported in [7] (T_{2f} = 1.2 ms, T_{2s} = 7 ms), which leads to $\tau_1 = TE$ = 2.5 ms. The optimum preparation time for ^{23}Na is reached for a higher value of about $\tau_1 = TE \approx 7$ ms.

Standard ^{23}Na and ^{35}Cl images of a human brain are compared to ^{35}Cl TQF data in Fig. 2. ^{35}Cl TQF images can be acquired in T_A = 70 min with an isotropic resolution of (15 mm)^3. Due to the partial volume effect, resolution is too low to distinguish brain parenchyma and the ventricles. However, resolution cannot be reduced while keeping T_A on a reasonable value as can be seen in Fig. 3. A ^{35}Cl TQF image with an isotropic resolution of (11 mm)^3 is shown, which is acquired using the same sequence parameters as in Fig. 2. SNR is too low to provide a useful contrast.

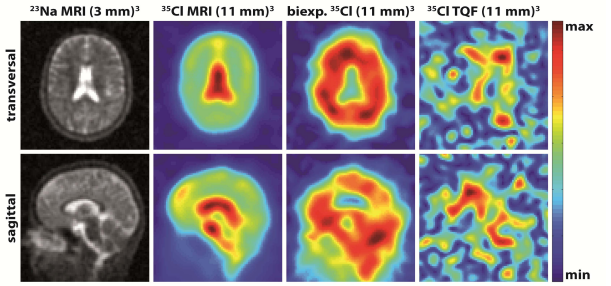

Fig.3: ^{23}Na, ^{35}Cl, biexponentially weighted ^{35}Cl and ^{35}Cl TQF images of the healthy human brain. Ventricles and brain parenchyma can be distinguished in ^{35}Cl and biexponentially weighted ^{35}Cl images. SNR of ^{35}Cl TQF image is too low to provide useful contrast.

The raw data of the ^{35}Cl TQF image was used to generate a single-quantum filtered image. A standard ^{35}Cl image with short echo time (*TE* = 0.4 ms) was acquired additionally during the experiment (cf. Fig. 3). These images were employed for calculating a biexponentially weighted image which is shown in Fig. 3. Signal originating from the ventricles is suppressed and can be clearly distinguished from brain parenchyma, which exhibits the highest signal. The location of the ventricles is validated by the comparison with ^{23}Na images.

CONCLUSION

In this work we present the first *in vivo* biexponentially weighted ^{35}Cl images and provide optimized sequence parameters for ^{35}Cl TQF imaging. Selective imaging of ^{35}Cl nuclei which are exposed to quadrupolar interaction, i.e. intracellular ^{35}Cl, is now feasible with better resolution in the same measurement time as compared to TQF ^{35}Cl imaging.

REFERENCES [1] Pond et al., J Neurosci (2006) 26: 1396-1406, [2] Jentsch et al., J Physiol Rev (2002) 82: 503-568, [3] Alvarez-Leefmans and Delpire, *Physiology and Pathology of Chloride Transporters and Channels in the Nervous System* (Academic, San Diego, 2009), [4] Cameron et al., Cancer Res (1980) 40: 1493-1500, [5] Gilles et al., In Proc. ISMRM (2013): 1993, [6] Benkhedah et al., Magn Reson Med (2013) 70: 754-765, [7] Nagel et al., Radiology (2013)

ACKNOWLEDGEMENTS Parts of the work were founded by the National Center for Tumor Diseases Heidelberg (NCT) and the Deutsche Forschungsgemeinschaft (DFG) under NA736/2-1.