A comparison of Inversion Recovery (IR), Triple Quantum Filtered (TQF) and Double Quantum Filtered with Magic Angle Excitation (DQF-MA) ^{23}Na MRI of human skeletal muscle

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Target audience: To researchers involved in seeking biomarkers for muscle-related pathologies

Purpose

Over the past two decades, ^{23}Na MRI has become a widely used technique to noninvasively determine the tissue sodium concentration. Moreover, several techniques to gain information about the sodium ions' molecular environment, mainly to distinguish intracellular and extracellular sodium, have been developed. Inversion recovery (IR) MRI is used to reduce signal of free sodium based on differences in T1 relaxation times [1]. Multiple quantum filtered (MQF) techniques exploit differences in quadrupole interaction due to motional restriction (triple quantum filtration – TQF) [2] or binding to anisotropic structures (double quantum filtration with magic angle excitation – DQF-MA) [3]. In this work, a comparison of IR, TQF and DQF-MA ^{23}Na MRI images of human lower leg was performed to characterize healthy skeletal muscle tissue. Therefore, SNR ratios between these techniques were evaluated for different muscle regions.

Methods

Pulse sequences were implemented on a 3-Tesla whole-body MR system (Magnetom Skyra, Siemens Healthineers, Erlangen, Germany). A single-resonant ^{23}Na birdcage coil (Stark Contrast, Erlangen, Germany) was used. All ^{23}Na images were acquired using a density-adapted radial readout scheme with anisotropic spatial resolution [4]. IR imaging was performed with the following parameters: TR = 124 ms, TE = 0.3 ms, TI = 34 ms, $(\Delta x)^3$ = 4x4x20 mm^3, T_{ACQ} = 9:50 min. MQF measurements (all parameters given for TQF/DQF-MA): TR = 150 ms, TE = τ = 5/1 ms , $(\Delta x)^3$ = 10x10x25/12x12x24 mm^3 , T_{ACQ} = 10:34/8:43 min. Additionally, conventional ^{23}Na images were acquired to estimate the total sodium content (TR = 50 ms, TE = 0.3 ms, FA = 80°, $(\Delta x)^3$ = 3x3x15 mm^3, T_{ACQ} = 6:53 min). The lower leg of five healthy volunteers (1 male, 4 female, age 24.9 ± 2.7 years) was examined together with four reference tubes containing NaCl solution (20 mM and 40 mM) with and without 4% agarose gel.

Results

Fig. 1 shows conventional ^{23}Na images (a) of two healthy volunteers together with IR (b), TQF (c) and DQF-MA images (d). Both IR and TQF sequences suppress signal of NaCl reference tubes originating from free sodium nuclei. In the DQF-MA images, all reference tubes are absent as neither NaCl solution nor agarose gel possesses a static quadrupolar coupling. SNR within tibialis anterior, soleus and gastrocnemius medialis muscles was evaluated in all images and normalized to corresponding voxel size and acquisition time. Results are summarized in Table 1. Soleus shows highest SNR in total sodium as well as IR and TQF images. In contrast, DQF-MA SNR is slightly enhanced in tibialis anterior. Additionally, normalized SNR ratios of IR, TQF and DQF-MA compared to total sodium were calculated (see Table 2). It was found that IR/^{23}Na ratio is highest for soleus, while both TQF/^{23}Na and DQF-MA/^{23}Na SNR ratios are highest for tibialis anterior.

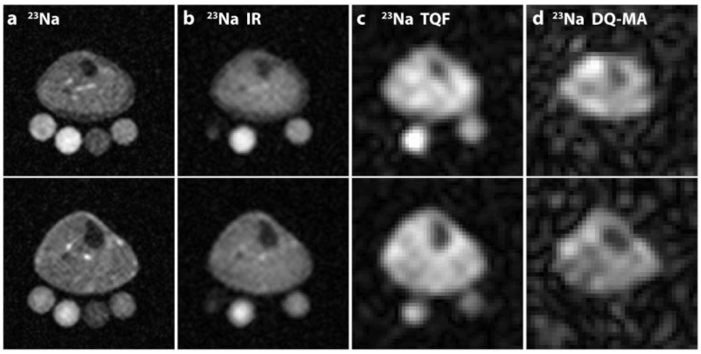

Figure 1: *Conventional ^{23}Na lower leg images (**a**) of two healthy volunteers are compared to IR (**b**), TQF (**c**), as well as DQF-MA ^{23}Na images (**d**). The reference tubes scanned together with the leg contain the following solutions (from left to right): NaCl (40 mM), NaCl (40 mM) + 4% agarose, NaCl (20 mM), NaCl (20 mM) + 4% agarose.*

Discussion

As can be seen in Fig. 1b, not all signal intensity arising from free sodium (NaCl solution) is suppressed using the IR method, mainly due to B_1-inhomogeneities. In total, TQF results in a better suppression of free sodium (Fig. 1c). However, quantification is more difficult using MQF techniques due to reduced SNR and their dependence on the applied preparation time. Additionally, for quantification of DQF-MA images, a reference exhibiting an anisotropic structure would be necessary, e.g. xanthan gel (see [3]). Moreover, the short TR of 50 ms used for the acquisition of the conventional ^{23}Na image results in a T1 weighting that might distort the presented ratios. By knowing the individual T1 values this could be corrected.

Conclusion

Inversion recovery and multiple quantum filtered ^{23}Na imaging can be used to gain information about the molecular environments of sodium nuclei. Using the presented measurement protocols, these techniques are feasible in clinically practicable acquisition times (≤10 min). The examined muscular regions show different behavior in the IR/^{23}Na, TQF/^{23}Na as well as DQF-MA/^{23}Na SNR ratios compared to the total sodium content. Therefore, these ratios may represent an additional measure for certain muscle-related pathologies, e.g. muscular dystrophies or channelopathies.

Table 1: *SNR of ^{23}Na, IR, TQF and DQF-MA images normalized to voxel size and acquisition time (n = 5).Values are given relative to the maximum value (^{23}Na SNR for Soleus).*

	Normalized SNR (a.u.)		
	Tibialis Anterior	Soleus	Gastrocnemius Medialis
^{23}Na	0.91 ± 0.04	1.00 ± 0.04	0.96 ± 0.04
IR	0.48 ± 0.03	0.62 ± 0.02	0.53 ± 0.03
TQF	0.11 ± 0.01	0.12 ± 0.01	0.11 ± 0.01
DQF-MA	0.043 ± 0.003	0.039 ± 0.002	0.039 ± 0.003

Table 2: *Normalized SNR ratios of IR, TQF and DQF-MA images compared to total ^{23}Na content (n=5).*

	Ratios of normalized SNR		
	Tibialis Anterior	Soleus	Gastrocnemius Medialis
IR/^{23}Na	0.55 ± 0.04	0.62 ± 0.03	0.55 ± 0.04
TQF/^{23}Na	0.14 ± 0.01	0.12 ± 0.01	0.12 ± 0.01
DQF-MA/^{23}Na	0.050 ± 0.004	0.038 ± 0.003	0.040 ± 0.003

References

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