Comparison of Cartesian and Radial ^{23}Na MRI for Visualization of Intracellular Sodium Accumulation in Patients with a Muscular ^{23}Na Channelopathy

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Introduction

Elevated ^{23}Na MR image intensity has been shown to correspond to high tissue ^{23}Na concentration due to intracellular sodium accumulation [1]. The ^{23}Na signal *in-vivo* decays biexponentially, the short component T_{2s}=0.5-3ms, and the long component T_{2l}=15-30ms. To measure the total ^{23}Na signal sequences with TE<0.5ms are necessary. Previous studies have used a 3D radial technique to quantify the ^{23}Na content in the muscle of patients with myotonic distrophy or osteoarthritis [2]. The purpose of this study was to visualize the intracellular sodium accumulation and the effects of specific therapy in patients with the inherited sodium channelopathy (paramyotonia congenita, PC).

Materials and Methods

Five patients with confirmed PC and 10 healthy volunteers were examined on a 1.5 T clinical MR system (Symphony, Siemens AG Medical Solutions, Germany) using a single-resonant (16.84MHz) surface coil (Rapid Biomed GmbH, Germany). ^{23}Na MRI was performed before and after local cooling and exercising of the left lower leg. The examination was repeated the next day and, in patients with PC, after 4 days of oral medication with a sodium channels blocker. The imaging protocol comprised T_1 and T_2 weighted ^{1}H sequences, a ^{23}Na 2D cartesian gradient-echo GRE (TR=13ms, TE=3.53ms, FOV=340mm, matrix 128×128, slice thickness TH=30mm, BW=190Hz/pixel, N_{acq}=300, T_{acq}=8min) and a ^{23}Na 2D radial GRE (TR=13ms, TE=0.6ms, FOV=500mm, matrix 64×64, TH=30mm, BW=190Hz/pixel, N_{acq}=400, T_{acq}=5.5min) sequence. ^{23}Na FID's of each leg were also acquired (TR=1000ms, TE=0.2ms). A 3D radial GRE sequence as described in [3] (TR=4ms, TE=200µs, FOV=500mm, BW=500Hz/pixel, 5000 projections×64 samples/projection, N_{acq}=30, T_{acq}=10min) was applied to acquire images of both legs after cooling, using a double-resonant (16.84MHz/63.6MHz) birdcage coil (Rapid Biomed GmbH, Germany). Images were reconstructed online with a gridding algorithm (Kaiser-Bessel window and a rho filter modified to correct for undersampling). The FID's were fitted to a biexponential decay to evaluate the fast and slow component of the T_2 relaxation time and ROI's were selected in the ^{23}Na images using a physiological saline solution as reference. The experimentally induced paresis was scored by a neurologist.

Results

Fig. 1 shows images of a patient with PC. In the 3D radial images acquired with the birdcage coil, the enhanced signal regions on the upper part of the legs do not relate to pathological changes, but B_1 field inhomogeneity due to the fact that both legs fit tightly inside the coil. B_1 field inhomogeneity is seen with with the surface coil, which has a penetration depth ~ 7.8cm. The pathologic signal increase can however be evaluated because the right leg used as reference is positioned at the same distance from the coil and thus submitted to a similar B_1 field. The radial images suffer from blurring due to the decay of the short T_2 component during data acquisition. The cartesian acquisition occurs after the short T_2 component has already decayed, and thus does not suffer from blurring. All 5 patients with PC developed considerable weakness of the left foot after local cooling and exercise, which was absent in volunteers. In patients with PC, the ^{23}Na FID's showed a 17% increase in the short-to-long T_2 component ratio and a signal increase in the affected area of the leg could be observed in the ^{23}Na images (Fig. 1.d,f,g). Volunteers, in contrast, showed no significant alteration. After sodium channel blockage in patients, cooling and exercise induced almost no weakness, and ^{23}Na MRI remained unchanged. In patients with PC, the CNR between the cooled leg and the reference leg is about 8% for the 2D cartesian, 11% for the 2D radial and 10% for the 3D radial. The 3D radial data must be corrected by a factor of ~3 reflecting the tenfold higher number of averages of the 2D images with respect to the 3D data set. This implies a 67% and 73% higher CNR of the 3D radial images with respect to the 2D radial and the 2D cartesian images respectively.

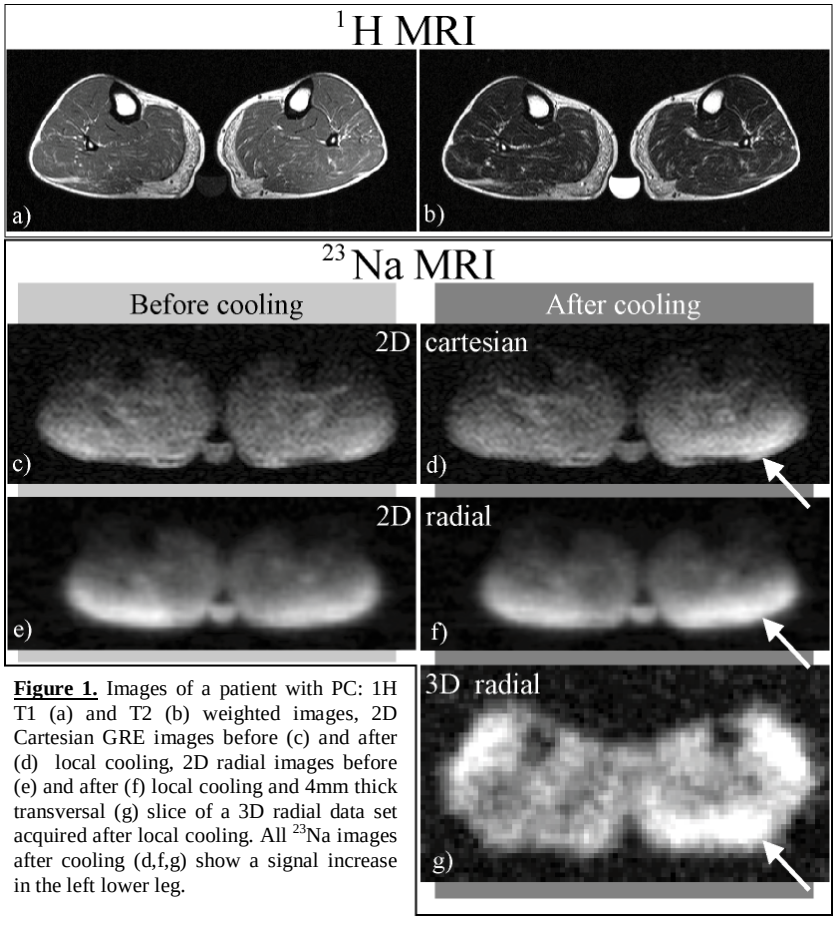

Figure 1. Images of a patient with PC: 1H T1 (a) and T2 (b) weighted images, 2D Cartesian GRE images before (c) and after (d) local cooling, 2D radial images before (e) and after (f) local cooling and 4mm thick transversal (g) slice of a 3D radial data set acquired after local cooling. All ^{23}Na images after cooling (d,f,g) show a signal increase in the left lower leg.

Discussion

The 17% increase in the short-to-long T_2 component ratio and the signal increase in the ^{23}Na images reflects the intracellular sodium accumulation. The 3D radial technique has the highest sensitivity, due to the shorter TE that allows for the acquisition of the total ^{23}Na signal. This study proves that ^{23}Na MRI visualizes intracellular sodium accumulation that is associated with muscle weakness in patients with PC. Furthermore, effects of a specific therapy can be monitored. This experiments, however, suffer from long measurement times due to the low SNR of ^{23}Na MRI. Future work will focus on the quantification of the ^{23}Na content in muscle.

References

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