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Fast and unconditionally safe in vivo MR head protocol for home-made coil prototype assessment at 7T

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Abstract. Depending on the local IRB (Internal Regulation Board) regulations for safety reasons, homemade RF coil prototype assessment through an in vivo experiment can be painful and lengthy administrative process. It includes to document simulations and experimental validations on phantom before being able to proceed. The situation can be even worse, if for some reasons, once it has passed all the acceptance stages, the coil does not deliver as expected in vivo. The process to maybe then rebooted.

In this work, we introduce the concept of unconditional safe MR protocol allowing to safely use homemade coil in vivo, at any step of the RF coil development, securing valuable information for the developer, and making sure that neither local nor global SAR limits will be ever reached anywhere in the organ to image. The protocol includes in particular a fast B1+ mapping, which is essential to assess coil behaviour. The strategy can be easily extended to more contrasts, other organs and other magnetic field strengths.

1. Introduction

Ultra-High-Field (UHF) Magnetic Resonance Imaging (MRI) scanners hold great promises for clinical and neuroscientific researches. RF coil technologies, at the state of the art, have had hard time to deliver all the expectations put in UHF. The first reason, why they failed, is certainly the heterogeneous excitation of the nuclear spins obtained with a classic coil design, which typically leads to shadows across the human brain images, making the impacted regions non-exploitable. Parallel Transmission (pTx) is the dominant strategy to solve the issue, but such system holds also some weaknesses including long calibration time and a relative inefficiency because of strong coupling between coils [1,2]. Attempts to mitigate the B1+ field has also been done including in the RF coil high dielectric constant materials [3] or metamaterials [4,5]. Whatever the chosen strategy, RF coil delivers energy inside human body to excite the nuclear spins that will be used to form an image. This energy is also partially absorbed by the

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biological tissues and translates into a rise of body temperature. Therefore, it is necessary to be sure that globally and locally temperature stays within safe limitations. Because it is not possible to measure the temperature in real-time during an MR examination, regulation relies on Specific Absorption Ratio (SAR) limitations. The norm is based on IEC 60601-2-33 recommendations [6]. This question is specially scrutinized at UHF because local SAR can be reached faster than global SAR promoting insidious hotspots in the imaged organ [7]. Depending on the local IRB (Internal Regulation Board) regulations, homemade RF coil prototype assessment though an in vivo experiment can be painful and lengthy administrative process. It includes to document simulations and experimental validations on phantom. It relies on very well engineered processes which warrant that the SAR limitations are never exceeded [8,9] with any RF excitation scenarios for a given RF coil.

In this work, we propose unconditional MR protocol allowing to safely use home-made coil in vivo, at any step of the RF coil development, securing valuable information for the developer, and making sure that neither local nor global SAR limits will be ever reached. The idea is to warrant safety regardless of the coil to be used by adapting sequence parameters to deliver ultra-low averaged power. Within this mode if the whole RF power would focus in a single 10g of biological tissue, it would not exceed the regulatory global and local SAR limits even for this piece of tissue. Hence, the goal is to identify MR sequence parameters that could be played with such low input power and still deliver valuable MR images within a decent acquisition time (TA). In such conditions, it becomes possible to acquire MR image in vivo without any prior coil validations.

2. Materials and Methods

Demonstration has been carried on a Magnetom 7T MRI scanner (Siemens Healthineers, Erlangen, Germany) equipped with a SC72 whole body gradient (max gradient amplitude 100mT/m, and slewrate 200 T/m/s) with a standard transceiver birdcage (Invivo Corp, Gainesville, FL, USA). In vivo acquisitions have been done under local IRB rules on one healthy volunteer.

The calculation of the relevant sequence parameters has been done based on the fact that the calibration of the reference pulse (REF), a 500us boxcar 90° pulse, would require the full power available at the port of the coil (e.g. 8x1kW for configuration we used) which is again very restrictive because the coil would be excessively inefficient in this situation. Four sequences have been identified that can be played within 7min as described in the Table for single channel system. For pTx system, 1min per additional channel is required to monitor B1+. The so-called restricted SAR mode protocol relied on gradient recalled echo (GRE) for B0 shimming, XFL [10] for B1+ mapping and localizer and Echo-Planar (EPI) for Eddy current investigations.

3. Results

In Table, the sequences parameters are displayed with an estimation of the worst global and local SAR possible while using the worst possible REF. It is well below the limit even in the case where all the power would focus inside 10g of tissue. On Figure, the optimal setup of the XFL and the restricted mode version shows a very good agreement.

Table: *Parameters of the identified "restricted SAR mode" sequences. They have been validated on phantom and in vivo using a single channel volume coil to ensure to be sensitive enough to get reliable information on coil prototype behaviors.*

Goal	**localizer**	**B0 map**	**B1+ map**	**EPI**
Sequence type	**2D XFL (only ref scan)** [2]	**2D GRE**	**2D XFL**	**2D EPI**
Exc RF pulse type	Sinc	Sinc	Sinc	Sinc
Duration (us)	1000	1000	1000	1000
FA (°)	3	5	3	10
RF saturation	-	-	RECT	-
Sat duration (us)	-	-	1000	-
Sat FA (°)	-	-	60	-
REF Voltage (V)	470	470	470	470
TR (ms)	20000	400	20000	10000
Ny	128	64	64	64
Multislice mode	Sequential	Sequential	Sequential	Interleaved
Spatial resolution (mm^3)	2x2x4	4x4x4	4x4x4	4x4x4
Slice number	3	5	3	3
TA	**2min**	**2min**	**2min**	**10s**
SAR_{local} (W/kg) - 6min [10s]	**6 [12]**	**6.6 [6.6]**	**3.6 [8.3]**	**1.63 [1.63]**
SAR_{global} (W/kg) - 6min [10s]	**0.012 [0.024]**	**0.013 [0.013]**	**0.007 [0.016]**	**0.033 [0.033]**

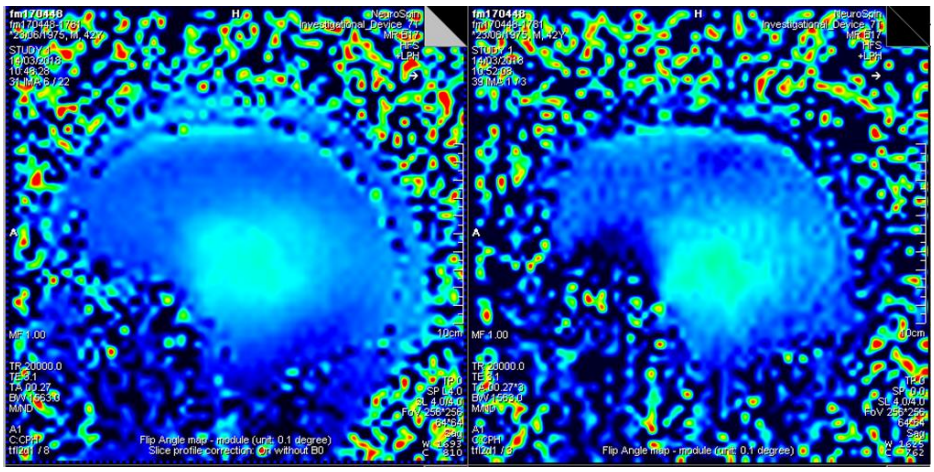

Figure : *In vivo sagittal views of a B1+ head maps acquired respectively from left to right with optimal XFL protocol and with "Restricted SAR mode" setting with InVivo Corp transceiver birdcage coil at the same resolution. The restricted SAR mode version brings SAR estimation toward zero. If all power focused into 10g of tissue, local SAR would only achieve 3.6W/kg.*

4. Discussion and conclusions

We successfully demonstrated the possibility to acquire reliable information using sequence powering very limited RF deposition with a short TA making it compatible with in vivo acquisition. Using this protocol, no prior simulation of any kind is needed but no change in the sequence parameters is allowed during the examination. The sequences should therefore be compiled into a "Restricted SAR mode" version to lock the sequence parameters.

More contrasts could be considered in this mode especially T1 using Turbo FLASH (TFL) like sequence and T2* weighted with GRE sequence. T2 might be more challenging in a decent time. The demonstration was done on purpose with a transceiver head birdcage, which is known to be weak in Signal to Noise Ratio. Thus, any tests on state of the art receiving coil array should return even better results.

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