A Simulational Study on the Homogeneity of Dual-Tuned Birdcage Coils

W. M. Potter[1,2], L. Wang[1,2], K. McCully[3], and Q. Zhao[1,2]
[1]Physics and Astronomy, University of Georgia, Athens, Georgia, United States, [2]Bioimaging Research Center, University of Georgia, Athens, Georgia, United States,
[3]Kinesiology, University of Georgia, Athens, Georgia, United States

Introduction

Dual-tuned ($^{1}H/^{31}P$) birdcage coils have become a well known and widely used tool for magnetic resonance spectroscopy (MRS). Oxidative metabolism indices, such as phosphocreatine [PCr], are important indicators of biochemical processes. MRS of phosphorous (^{31}P MRS) is well suited to monitor these processes in both skeletal muscles and neuronal synaptic development in human brains. However, the ^{31}P MRS signal sensitivity is usually low due to low concentrations of the nucleus and magnetic field inhomogeneity from currently available commercial surface coils. The goal is to create a very homogeneous B1 field inside the coil. The practicality of building a dual-tuned coil, however, can be troublesome due to many factors such as coil structure (e.g., # of legs/rings, dimensions) and biological objects to be imaged. In this abstract, the homogeneity comparisons for the 8-leg, 16-leg, and the 24-leg, 4-ring low-pass birdcage coils are presented with the presence of simulated human head and thigh modules.

Methods

The dual-tuned low-pass birdcage coil uses 4 conducting rings connected with conducting legs that form three individual sections, an inner section and two outer sections. The outer section is for ^{1}H imaging (127.72MHz for Hydrogen at 3T) and the inner section is for ^{31}P MRS (51.7MHz for Phosphorus at 3T). The optimization of the physical parameters of a dual-tuned coil has been toyed with in the past (1-4). However, the coil for this experiment is intended for imaging of the adult human thigh and head. The diameter, length of the inner coil, and length of the outer coil were set as 23.45cm, 19.54cm, and 3.26cm respectively to fit both anatomies, with consideration of the optimum dimensions found by Duan et al. (1). Using the above dimensions, simulations were run with a finite difference time domain program, xFDTD (Remcom, State College, PA.), to calculate and map the magnetic field. Rather than tuning capacitors at each leg of the inner birdcage coil, the magnetic field is generated with sinusoidal voltage sources placed in series with each leg, at a frequency of 51.7MHz and phase shifted to form a sinusoidal current distribution. For example, the shift of each leg of an 8-leg coil would be: 0, 45, 90, 135, 180, 225, 270, and 315 degrees. Capacitances placed on the outer coils were estimated according to the Penn State NMR birdcage builder software, which were 6.19pF, 3.39pF, and 2.32pF for the 8-leg, 16-leg, and 24-leg coils, respectively. One full cycle of a 51.7MHz excitation wave was simulated and the magnetic field generated around the mid-point of the cycle is analyzed for homogeneity in the xy-plane (transverse) and the yz-plane (longitudinal) as shown in Fig.1. The analysis was performed in free space and presence of biological objects, a human head and the thigh modules (Virtual family models, IT'IS Foundation, Switzerland), respectively.

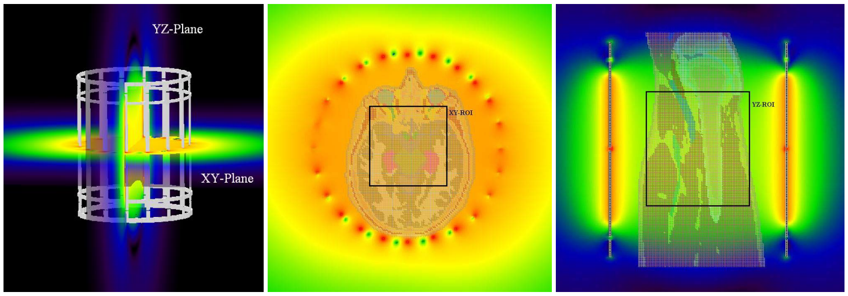

Figure 1. Left: Four-ring, 16-leg dual-tuned birdcage coil in free space with simulations of the total magnetic field in the xy-plane and the yz-plane; Middle: the xy-plane region of interest for the 24-leg coil with the head module inside; Right: the yz-plane region of interest for the 8-leg coil with the thigh module inside.

Table 1. The recorded values for the mean homogeneity and standard deviation for the xy-plane and yz-plane are listed for the 8-leg, 16-leg, and 24-leg coils with free space, the human thigh module, and the human head module inside.

	8-Leg		**16-Leg**		**24-Leg**	
	Mean, % xy / yz	Standard Deviation xy / yz	Mean, % xy / yz	Standard Deviation xy / yz	Mean, % xy / yz	Standard Deviation xy / yz
Free space	2.41 / 4.54	1.55 / 2.85	2.02 / 4.62	1.29 / 2.92	2.08 / 4.60	1.35 / 2.89
Human Thigh	3.11 / 4.67	2.37 / 3.04	2.48 / 4.62	1.8 / 2.96	2.58 / 4.65	1.84 / 2.96
Human Head	2.45 / 4.81	1.87 / 3.03	2.02 / 4.84	1.54 / 3.06	2.1 / 4.85	1.5 / 3.00

Results and Discussion

Using the simulated magnetic field data, the homogeneity was calculated inside a region of interest (ROI) about 10cm by 10cm (see Figure 1) with the equation, $\frac{|B_{i,j} - B_{mean}|}{B_{mean}}$, where $B_{i,j}$ is the magnetic field at point (i,j) in the ROI. The values that were found included the mean homogeneity and the standard deviation. The trend in the data for the xy-plane shows that the mean homogeneity and the standard deviation improve from the 8-leg coil to the 16-leg coil , which is expected, but then they slightly deteriorate from the 16-leg coil to the 24-leg coil. The hypothesis is that with the more legs the coil has, the greater the homogeneity should be and the smaller the standard deviation should get. However, this is not the case in this simulation, perhaps because of the selected dimensions of the actual coil. The dimensions used were a linear scaling of the optimum dimensions found by Duan et al. (1) for a 16-leg dual-tuned coil. The optimum length of a birdcage coil with more legs would be longer than a birdcage with fewer legs. This is probably why the 16-leg coil has the best homogeneity for these simulations. For the yz-plane the mean homogeneity is very close for the 8-leg coil, the 16-leg coil, and the 24-leg coil. The standard deviations are also comparable for each of the various dual-tuned coils. The magnetic field created in the yz-plane has an "X" like pattern and doesn't change very much as the number of legs on the coil is increased. This may contribute to the similar mean homogeneity and standard deviation.

In summary, the simulation results show that there is an improvement in the 16-leg dual-tuned birdcage coil over the 8-leg dual-tuned coil when comparing homogeneity of the xy-plane and therefore eventual signal levels of oxidative metabolism indices like the resynthesis rates of phosphocreatine after exercise. However, the improvement of field homogeneity in the 24-leg coil may need a restructure of the length of its inner and outer sections.

Acknowledgements

This work was partially funded by NIH HD039676. Also, we'd like to thank Jason Langley for his contributions along the way.

Reference

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