Single Voxel Spectroscopy of the Pons: Shimming, Quantitation, and Reproducibility Issues at 3T

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Introduction

Abnormalities in ratios of brain metabolite peaks were previously measured via magnetic resonance spectroscopy (MRS) at 1.5T in the pons and basal ganglia [1,2] and in bilateral hippocampus [3] of Gulf War Syndrome patients. For a more complete understanding of the chemical changes in the brain with disease or age, reproducible absolute concentrations of metabolites need to be obtained. The ability to produce high-quality ^{1}H MRS data is critically dependent upon proper shim adjustment to obtain a uniform magnetic field over the volume of interest (VOI). In certain areas of the brain (e.g. pons, and other brain stem regions), where the magnetic susceptibility is highly inhomogeneous, proper shimming of the magnetic field is challenging. Reproducibility (e.g. same subject, different runs) can also be a technical challenge. The main issues are (1) reproducible voxel positioning, (2) different shims for specific regions in (a) repeated sessions in the same subject or (b) in different subjects, (3) possibly different flip angle spatial distributions, and (4) subject motion. Finally, the water peak in the VOI can be used to correct residual imperfections in line shape and width, and as a reference for absolute quantification of metabolite concentrations [4,5].

Methods

A standard Siemens single-voxel sequence (SVS PRESS) was used on a Siemens 3T Trio TIM with the following parameters: TR/TE/NS = 2000ms/30ms/128, voxel (centered in the pons) volume = 5.4 mL (18 mm x 15 mm x 20 mm), spectral width = 2000 Hz, water suppression bandwidth = 50 Hz, data points = 1024, acquisition time = 4:24 min. After manual shim the water line width in the pons was 15 Hz (except session 3, see below). Post-processing was performed using LCModel [5,6]. An unsuppressed water spectrum was also acquired for eddy current compensation and absolute quantitation. We performed the same SVS measurement on a healthy volunteer in 3 sessions, 4 times in each single session with the same voxel, same shim, and same subject position (controlled as well as possible).

Results and Discussion

Good quality high-resolution and high-contrast localizer images used for proper voxel positioning alleviate the problems due to inadequate reproducibility of voxel positioning. The 3DShim Siemens utility (applied twice in succession in the default algorithm for the Advanced Automatic shim) applies to all standard Siemens' spectroscopy sequences and provides an approximation of the required shim currents. However, manual adjustment of the shim currents (interactive shim) produces better results (water half-height line width of 15-18 Hz and key metabolite line widths of 5-7 Hz) in the pons and other difficult areas. Higher-order shims as well as first-order linear shim adjustments are usually required. An example pons spectrum is shown in Figure 1. The reproducibility of these measurements is illustrated in Table 1. Intra-session, intra-subject metabolite variability in the four sequential acquisitions is within the 95% confidence intervals based on the Cramer-Rao lower bounds calculated by LCModel. This is not surprising, considering the fact that the shim is the same and the subject motion was kept to a minimum. Differences in the inter-session results (between sessions 1 and 2) are statistically insignificant. When shim quality is lower (see Table 2, corresponds to automatic shim adjustment and water line width of 24 Hz) the metabolite detection power decreases, and it might not be sufficient depending on the application. Additionally, using balanced one-way ANOVA we determine that the calculated mI and Cr concentrations are significantly different (lower) in session 3. In certain cases even the best shimming does not provide a sufficiently narrow line, so additional post-processing methods such as reference deconvolution [4] might need to be utilized to further improve the analysis.

Conclusion

Shimming and reproducibility are of crucial importance for performing quantitative spectroscopy studies. In the manual shim mode our Siemens 3T Trio TIM system is capable of providing an acceptable shim even in areas of highly inhomogeneous magnetic susceptibility, as illustrated by the pons example. Reproducibility and quantitation are affected by many factors, shim quality being a very important one. Reliable voxel placement is an area where an immediate improvement is possible by utilizing high-resolution localizer images and minimizing subject motion. A future implementation of the Siemens AutoAlign feature into single voxel spectroscopy might provide even stronger benefits. Additionally, reference deconvolution [4] can be employed to further reduce line widths, improve line shapes, and ultimately help with quantitation. However, to fully transition from "institutional units" for metabolite concentrations to absolute concentrations, relaxation time measurements in vivo will be needed [7] as well as determination of the compartmentation in the human brain [8]. In general, the challenge is to obtain the most relevant and meaningful MRS information and data in a given measurement time, so careful optimization and planning is required [9].

Acknowledgments

References

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Figure 1. 3T ^{1}H MR spectrum of the pons of a normal subject processed using LCModel. Metabolites detected with acceptable reliability are shown in blue.

	Cr	Cr %SD	Glu	Glu %SD	GPC	GPC %SD	mI	mI %SD	NAA	NAA %SD
Sess. 1, Exp. 1	4.35	5	5.37	13	2.40	3	4.32	6	7.01	5
Sess. 1, Exp. 2	4.47	5	5.03	14	2.52	3	5.19	6	7.03	5
Sess. 1, Exp. 3	4.41	5	4.54	16	2.39	3	4.55	7	6.80	5
Sess. 1, Exp. 4	4.40	5	4.92	14	2.42	3	5.38	5	7.69	5
Sess. 2, Exp. 1	4.83	5	5.59	13	2.52	3	4.67	7	7.71	6
Sess. 2, Exp. 2	4.62	5	5.38	13	2.62	3	4.01	7	7.54	5
Sess. 2, Exp. 3	4.46	5	5.27	13	2.43	3	4.72	6	7.38	5
Sess. 2, Exp. 4	4.33	5	4.72	14	2.36	3	4.67	6	7.19	5

Table 1. Primary metabolite concentrations and % standard deviations (SD) as calculated by LCModel (Institutional Units). Water line width = 15 Hz.

	Cr	Cr %SD	Glu	Glu %SD	GPC	GPC %SD	mI	mI %SD	NAA	NAA %SD
Sess. 3, Exp. 1	3.62	8	4.68	18	2.41	5	3.89	9	6.76	9
Sess. 3, Exp. 2	3.93	8	6.52	13	2.14	6	4.33	9	6.83	9
Sess. 3, Exp. 3	4.61	7	4.85	20	2.46	5	3.30	13	6.96	11
Sess. 3, Exp. 4	3.74	9	4.72	22	2.15	6	2.89	17	7.76	9

Table 2. Same setup as in Table 1 but the shim quality of this session was lower (water linewidth of 24 Hz, key metabolite line widths of 8-12 Hz).