SNR Measurements in a Single Voxel MRS Experiment

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Introduction

The signal to noise ratio (SNR) is a commonly used value to determine the quality of all kind of signals. In clinical MR spectroscopy SNR has become a marker, which is used to estimate the quality of a spectrum, to predict reliability of the quantitative outcome or to control system stability in regular phantom studies [1]. A reliable and reproducible estimation of the SNR is a prerequisite for an appropriate and meaningful use. This study will demonstrate that SNR values automatically provided by standard processing tools often do not reflect the true SNR of a spectrum. Alternative methods for an improved estimation of the SNR in a single voxel MR spectroscopy experiment will be proposed and discussed.

Methods

All experiments were performed on a GE Signa Excite 3.0T (*General Electric Healthcare Technologies, Milwaukee, WI, USA*), MRI scanner running under software revision G3 using a standard quadrature transmit/receive volume resonator and the GE MRS HD Sphere, a 16 cm diameter spectroscopy phantom. Localized PRESS spectra were acquired at the center of the phantom. TE was chosen to be 35 ms, TR=1.5s, voxel volume=8ml, spectral resolution=2048 pts, bandwidth=5kHz and phase cycling=2. The number of averages "n" was stepwise increased starting with n=4 doubling the number of acquisitions to a total number of n=1024 acquisitions to compare determined SNR values with the expected increase of the SNR with the square root of n. In a second experiment, the number of averages was kept constant to 32 averages to monitor the reproducibility of the SNR measurement.

As a baseline measurement each phantom scan was followed by an identical acquisition where the RF source was switched off, and by a third scan where the phantom was removed from the coil while keeping all systems parameters, especially the system gains, constant. All spectra were automatically processed with the scanner build-in PROBE/SVQ reconstruction. In addition each set of raw data was processed on a Linux PC using a dedicated software package SAGE (*GE Healthcare Technologies, Milwaukee, WI, USA*) as well as the LCModel. A new approach for SNR estimation in single voxel MRS was introduced as demonstrated in Fig. 1. In the first step, the raw data of all phantom scans was line-by-line phase and frequency corrected, followed by a subtraction of always two adjacent lines in the time domain (Step 2). The result of the subtraction of adjacent frames very much depends on the stability of the data, thus sometimes an unwanted residual water signal will still be present as seen after FFT performed in step 3. A duplicated copy of the data was placed adjacent to the original spectrum (Step 4) and reduced to the central part spanning about 3800 Hz (Step 5) free of any residual water signal distortions. The noise level was calculated as the standard deviation (SD) of the remaining data points.

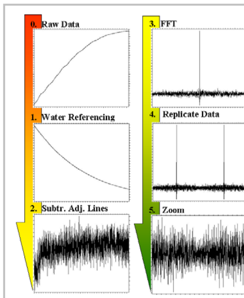

Fig.1: Processing flow chart to determine noise level of phantom spectra.

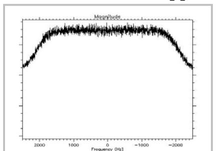

Fig.2: Magnitude of a pure noise spectrum.

Spectra acquired without the phantom or with RF source switched off were line by line Fourier transformed, averaged and reduced to ± 1900 Hz before calculating SD. Reducing the actual width of the area used for the noise calculation was derived from the magnitude spectrum shown in Fig. 2. Due to the acquisition filter, which prevents noise from being aliased back into the spectrum, the noise is damped at the edges of the spectrum. This damped noise area should not be taken into consideration for pure noise estimations. For the subtraction method, we found no significant difference between excluding and including the area of damped noise, thus the area was not excluded to keep processing simple.

Results

All spectra were successfully acquired, processed an evaluated. Fig. 3 shows the SNR values determined for a series of spectra acquired with increasing number of averages. As previously reported by others, the SNR values determined by the automatic PROBE/SVQ and the LCModel reconstruction do not follow the expected increase of the SNR by the square root of n [2]. The newly introduced subtraction method on the other hand follow precisely the expected behavior, with only very minor differences to the reference method using pure noise spectra acquired either without phantom or without RF. The algorithm used for the noise estimation determines the SNR results achieved with the automatic PROBE/SVQ reconstruction. The presented SNR number is not intended to be used as a true measure for system SNR but a quality guideline for in vivo spectra [3]. Furthermore, as already shown in Fig.2, a spectrum never has a totally flat baseline. If the intrinsic noise level of a spectrum is high, the signal SD is mainly defined by the noise. If the intrinsic noise level on the other hand is very low, e.g. due to higher number of averages, the main signal SD might now be defined mainly by a change in the baseline. A systematic baseline effect, which will increase proportional with the number of signal averages, can never be overcome by reducing the noise level, thus yielding constant SNR. A systematical "noise-pattern" can also be observed on the residual lines provided after LCModel processing, which are used for the SNR estimation. The LCModel uses a linear combination of a set of basis spectra to model the acquired spectrum. In a perfect world, the difference between acquired and modeled data would be pure noise. In the real world, there are systematical differences between the model data and the acquired spectra, which can be seen in Fig.4, where the residual line starts to show a systematical pattern with higher number of signal averages. The reproducibility of the SNR measurement shown was measured acquiring ten phantom spectra. The noise level determined by PROBE/SVQ showed highest variations of up to ± 9%, while the variations observed with the subtraction method or with the pure noise spectrum stayed below ± 3% (Fig.5).

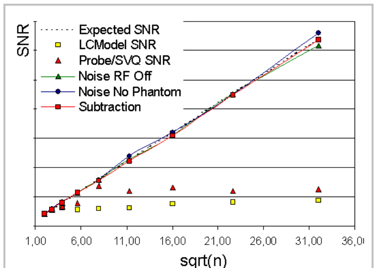

Fig.3: SNR (Noise) values with increasing number of averages measured with different approaches.

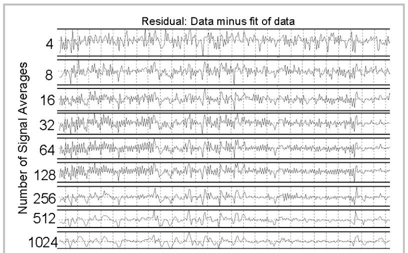

Fig.4: LCModel residual with increasing number of signal averages.

Discussion

This study has shown, that some of the SNR or noise level measurements provided by automatic spectroscopy processing tools are not reliable. SNR or noise values provided by these tools should be rejected as a scale for spectrum quality or system stability. The findings on the other hand should have no effect on the resulting metabolite concentrations and concentration ratios provided by these tools. An alternative simple method that could be used without acquiring additional data by applying a subtraction technique was introduced. Further studies are needed to proof whether this approach will also provide reliable SNR values for in vivo data. Using pure noise spectra by removing the phantom or switching off RF as a reference measurement was successfully implemented, but needs to be carefully applied. As the spectra do not contain any reference signal, any changes in signal gain might not be taken into account thus providing wrong numbers for the noise measurement.

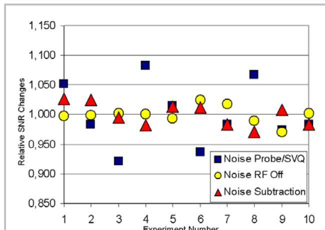

Fig.5: Reproducibility of SNR measurements.

References

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