Influence of parallel imaging and other reconstruction techniques on the measurement of signal-to-noise ratios

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Introduction

The signal-to-noise ratio (SNR) is an important quantity to describe the performance of an MRI system and is used e.g. for sequence and RF coil comparison, or quality assurance. Since the introduction of parallel imaging, the determination of SNR in non-accelerated and accelerated images has often been used to compare both approaches. In many recently published studies, e.g. [1–4], SNR calculation was performed by evaluating signal statistics in two separate regions of interest (ROIs) of a single image, one in the tissue of interest, the other in the image background, i.e. in the air [5]. The purpose of this study was to evaluate the validity of this approach in MRI experiments with multi-element surface coils and parallel acquisition techniques where a Rayleigh probability distribution and a homogeneous spatial distribution of background noise are not to be expected.

Theory

The most commonly used definition of the SNR of a single image voxel at position $\boldsymbol{r}$ is based on the variation of the signal intensity of the voxel in repeated "identical" acquisitions: **(1)** $\mathrm{SNR\_}N(\boldsymbol{r}) = \mathrm{mean}_n(I(\boldsymbol{r}, n)) / \mathrm{stddev}_n(I(\boldsymbol{r}, n))$, where $\mathrm{mean}_n(\,)$ describes the mean value and $\mathrm{stddev}_n(\,)$ the standard deviation over all repeated acquisitions indexed by $n = 1\ldots N$; $I(\boldsymbol{r}, n)$ is the signal intensity in repetition n, e.g. in a magnitude image. Since repeated acquisitions are time-consuming and may be influenced by systematic signal variations due to patient motion or physiological signal variations, simpler methods requiring fewer acquisitions are typically applied for SNR measurements. Using only two acquisitions, the average SNR in a ROI can be determined from the mean signal in this ROI and the standard deviation of the signal in the difference image (evaluated in the same ROI) **(2)** $\mathrm{SNR\_2} = (\sqrt{2})\,\mathrm{mean}_{\boldsymbol{r}}((I(\boldsymbol{r}, 1)+I(\boldsymbol{r}, 2))/2) / \mathrm{stddev}_{\boldsymbol{r}}(I(\boldsymbol{r}, 1)-I(\boldsymbol{r}, 2))$ [6]. Most often used is a technique based on the signal statistics in two separate ROIs of a single image, one in the tissue of interest ($\mathrm{ROI}_{\mathrm{tissue}}$), the other in the image background ($\mathrm{ROI}_{\mathrm{air}}$). The SNR is calculated **(3)** $\mathrm{SNR\_1_M} = (\pi/2)^{0.5} \times \mathrm{mean}_{\mathrm{tissue}}(I(\boldsymbol{r}, 1)) / \mathrm{mean}_{\mathrm{air}}(I(\boldsymbol{r}, 1))$ or **(4)** $\mathrm{SNR\_1_S} = (2-\pi/2)^{0.5} \times \mathrm{mean}_{\mathrm{tissue}}(I(\boldsymbol{r}, 1)) / \mathrm{stddev}_{\mathrm{air}}(I(\boldsymbol{r}, 1))$, using either the mean or the standard deviation of the background signal. The correction factors in the last two methods are required because of the Rayleigh distribution of noise in magnitude images [7].

Materials & Methods

To compare the results of SNR measurements using the four different methods described above, we acquired phantom images with an EPI and a fully gradient-balanced SSFP (TrueFISP) sequence with 100 repetitions. SNR_*N* (used as reference standard) was calculated from repetitions 5 to 100 (avoiding any initial non-steady-state images), SNR_2 from repetitions 50 and 51, and $\mathrm{SNR\_1_M}$ and $\mathrm{SNR\_1_S}$ from repetition 50. Images were acquired on a 1.5 T whole-body MRI system (Magnetom Sonata, Siemens, Erlangen, Germany) using a 1-channel quadrature head coil (CP_Head) and **(a)** standard reconstruction, **(b)** intensity normalization during reconstruction, and a 12-element dedicated parallel imaging array (12_Elm) using **(c)** standard reconstruction, **(d)** parallel imaging with the GRAPPA [8] reconstruction, and **(e)** parallel imaging with the mSENSE [9] reconstruction. The acceleration factor was 2 in (d) and (e). All other imaging parameters were kept identical in all measurements.

Results

The determined SNRs for the TrueFISP sequence are shown in Fig. 1. Depending on the acquisition and reconstruction, the SNRs calculated from one acquisition ($\mathrm{SNR\_1_M}$, $\mathrm{SNR\_1_S}$) show large deviations in comparison to the standard of reference SNR_*N*; in particular after intensity normalization during the reconstruction and with parallel imaging using the GRAPPA algorithm. Intensity histograms of the noise distribution deviate most clearly from the Rayleigh distribution in experiments (c) and (d). We found very similar results for the EPI acquisitions.

Discussion

Our results show that the conventionally measured SNR ($\mathrm{SNR\_1_{M/S}}$) may not agree with the true SNR in images after intensity normalization, multi-channel reconstruction, or parallel imaging. In particular, paradoxical results such as an increase of SNR with parallel imaging compared to conventional imaging with identical acquisition parameters may be observed (see e.g. $\mathrm{SNR\_1_M}$ in experiments (c), (d), and (e) or $\mathrm{SNR\_1_S}$ in (c) and (d)), perhaps explaining the "somewhat puzzling" g-factor<1 reported in [1].

The results of our study may have important implications for future comparisons of different conventional and parallel imaging reconstruction methods used for various clinical and methodological studies. In these studies, either the difference method or multiple acquisition method should be used.

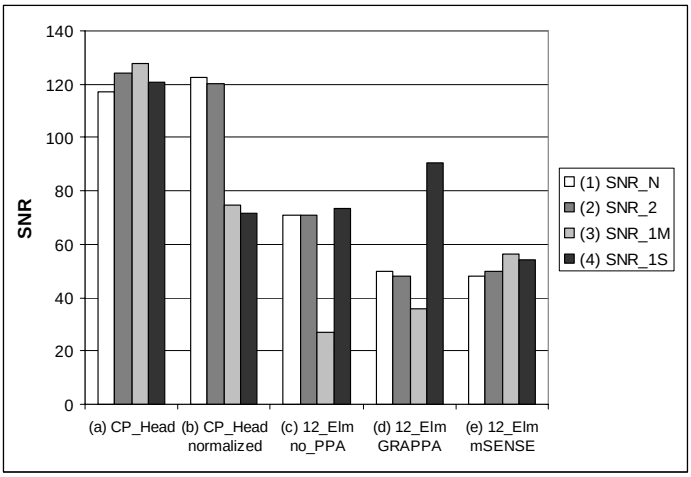

Figure 1: SNRs of phantom measurements with a TrueFISP sequence. Measurements with a 1-channel head coil (a, b) and a 12-element body coil (c, d, e) are compared without (a, b, c) and with (d, e) parallel imaging. SNRs are calculated from 95 repetitions (SNR_N), from a difference image of 2 repetitions (SNR_2), and from a single image using the mean (SNR_1M) and the standard deviation (SNR_1S) of the background signal.

References

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