Development and Evaluation of a New Method for Measuring of Signal-to-Noise Ratio in Magnetic Resonance Images

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Aims and objectives

Common physical evaluation method of the magnetic resonance (MR) image is signal-to-noise ratio (SNR). SNR is a value to express noise properties of images and used for device performance evaluation, daily quality control, and imaging sequence evaluation. It is thought that a signal level or noise level alone is unavailable for evaluation since signal intensity of MR image is a relative value. However, the rate of both the values can be kept, so that it is possible to evaluate the degree of noise by SNR. Various measurement methods of SNR have been already reported\(^1\)\(^-\)\(^3\)\(^)\). Two typical measurement methods are shown as follows.

1) Method recommended by the American Association of Physicists in Medicine (AAPM) and the National Electrical Manufacturers Association (NEMA)\(^2\)\(^)\)

Obtain two images under the same conditions and at the same location. The signal level is defined as the mean (Ms) in the area of interest set in an image of either. The noise level is calculated as follows: two images were subtracted and the standard deviation SD\(_{\text{sub}}\) within the area of interest is divided by \#2. Hereinafter these are referred to as NEMA method.

\[
\text{SNR} = \frac{\text{Ms}}{(\text{SD}_{\text{sub}}/\#2)} \quad \text{Equation 1}
\]

2) Method recommended by the EU\(^3\)\(^)\)

The signal level is defined as the mean (Ms) within the area of interest. The noise level is defined as the standard deviation (SDs). Hereinafter these are referred to as EU method.

\[
\text{SNR} = \frac{\text{Ms}}{\text{SDs}} \quad \text{Equation 2}
\]

The previous studies have reported that the NEMA method has little error of measurement and is also available for evaluation with parallel imaging technique\(^4\)\(^-\)\(^6\)\(^)\). However, this method requires imaging twice, and therefore it is difficult to make it apply to clinical image. Besides, there is a disadvantage that evaluation can be performed only when a structure noise is ignored. On the other hand, the disadvantage of the EU method is lower reproducibility because it greatly depends on the size of area of interest set.

This study aims to examine the precision and usability of our new SNR calculation method as a method to improve these problems.
Methods and materials

Summary of SNR calculation method using estimated formula of probability density function

The new SNR calculation method that we propose (hereinafter referred to as proposed method) is a method to calculate SNR as follows: estimate the probability density function of normal distribution for histogram obtained from all pixel values; calculate SNR using the mean ($\mu$) as a signal level and the standard deviation ($\sigma$) as a noise level obtained from the estimated formula. For estimation, we used the quasi-Newton method in which a Jacobian matrix is not implemented.

Simulation experiment

To evaluate the validity and the measurement accuracy of the proposed method, verification was performed using a simulation image. The simulation image was generated by the image analysis software (ImageJ, National Institutes of Health, Bethesda, Maryland). The matrix size was set to 192 x 192, and 16 bit grayscale was used. To simulate a uniform phantom, a circle with approximately 140 pixels in diameter was drawn in the center of the image, and the pixel value within the circle was set to 3200, and the rest of the pixel values were set to 0 to simulate air. A noise in MR image is known to be Rice-distributed, which is same as that a noise is Gaussian-distributed in the region where the signal exists and is Rayleigh-distributed in air region. Consequently, it is possible to simulate an image to which a noise with Rice-distribution was added by adding a noise with Gaussian distribution to an image to display an absolute value. Regarding the degree of the noise, the standard deviation was set to 10, 20, and 30, and therefore the theoretical SNR was 320, 160, and 106.7, respectively. For the obtained simulation image, SNR was calculated by the proposed method. For a comparison, calculation was performed by the NEMA method and the EU method similarly. In the NEMA method, two simulation images were required, so two images to which a noise was added to were generated separately. The size of area of interest to measure pixel levels was set to 75% of phantom areas.

Phantom experiment

For an MR device, the Magnetom Verio 3T was used. For both the transmitter and receiver coils, the Gantry coil was used. For phantom for SNR measurement, we used column container in acryl 15 cm in diameter and 10 cm in height which was filled with nickel sulfate solution.
The phantom for measurement was placed at the center of magnetic field of MR device, and left for 10 minutes or more before imaging in order to reduce the flow of the solution. The images were acquired with spin echo imaging sequences, under the following conditions: Repetition Time (TR), 500 ms; Echo Time (TE), 10.0 ms; slice thickness, 5.0 mm; matrix size, 192x192 pixels; field of view (FOV), 192x192 mm; Band width (BW), 465 Hz/pixel. The number of excitations was changed ranging from 1 to 4, and two images per excitation were acquired.

SNR in the obtained MR images was calculated by the proposed, NEMA, and EU methods. In the proposed method, to take account of MR device-specific image heterogeneity as well as single gauss model (SGM), estimation was also performed in the Gaussian mixture model (GMM) and both models were compared.

\[
\text{SGM}(x) = k\left(\frac{1}{\sigma^2} \times \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)\right)
\]

... Equation 3

\[
\text{GMM}(x) = m\left(\frac{1}{\sigma_1^2} \times \exp\left(-\frac{(x-\mu_1)^2}{2\sigma_1^2}\right)\right) + n\left(\frac{1}{\sigma_2^2} \times \exp\left(-\frac{(x-\mu_2)^2}{2\sigma_2^2}\right)\right)
\]

... Equation 4

* k, m and n is constant number

This GMM is expressed by composition of two probability density functions. For calculation of SNR, the mean and standard deviation of the probability density functions which estimated the center of the phantom were used. In the NEMA method and the EU method, measurement was performed with changing the size of area of interest (approximately 50%, 75%, and 100% of the phantom areas) to examine the dependence depending on the size of area of interest.

Results

Simulation experiment

For the simulation images, the results of SNR calculated by the proposed, NEMA, and EU methods are shown in Figure 1. The results of each signal level and noise level are shown in Table 1. In the NEMA method, the value, which divided \#2 as a coefficient, was
set to the noise level because the standard deviation was measured from the differential image. In all the calculation methods, each SNR was almost the same as the set value.

**Fig. 1**: Comparison of the SNR on the simulation images for the different analysis method (our devised method, NEMA method, EU method). The horizontal axis was preset SNR.

**References:** Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
Table 1: Comparison of three methods for the average and the standard deviation of the simulation image.

References: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP

**Phantom experiment**

The SNR in the phantom images obtained with the MR device was calculated by three kinds of methods. Each result is shown in Figure 2, 3, and 4. For the proposed method, the results of the SGM and GMM are shown. Typically, the histogram when the number of excitations was two and the estimated results in the SGM and GMM are shown in Figure 5 and 6. For the NEMA method and the EU method, we also show the results of which the size of area of interest was changed. Table 2 shows each signal level and noise level.
Fig. 2: Comparison of the SNR for the number of excitation on our devised method. The devised method was estimated formula of both SGM and GMM.

References: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
Fig. 3: Comparison of the SNR for the number of excitation on NEMA method. We measured the SNR while changing the size of ROI.

References: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
Fig. 4: Comparison of the SNR for the number of excitation on EU method. We measured the SNR while changing the size of ROI.

References: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
<table>
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<tr>
<th></th>
<th>our devised method</th>
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<th>NEMA method</th>
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<th>EU method</th>
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<td></td>
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<td>75%</td>
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<tr>
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<td>56.1</td>
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<tr>
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<td>59.5</td>
<td>103.1</td>
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</table>

**Table 2**: Comparison of three methods for the average and the standard deviation of the phantom images.

**References**: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
**Fig. 5**: Histogram of the pixel value when the number of excitation set "2" and, a formula was estimated by using the SGM.

**References**: Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP
Fig. 6: Histogram of the pixel value when the number of excitation set "2" and, a formula was estimated by using the GMM.

**References:** Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine - Nagoya/JP

In all the measurement methods, the SNR was increased as the number of excitations was increased; however, it was only the NEMA method where the SNR was equivalent to the value multiplied by the route of the number of excitations. Generally, the SNR of the NEMA method was higher than that of the EU method and that of the proposed method. The results of the proposed method indicated that the signal level of the SGM and that of the GMM were similar but the noise level was higher in the SGM than the GMM; thus the SNR was higher in the GMM. The histogram and both the estimated results indicated that the fitting precision of GMM was higher than that of the SGM. Although the size of area of interest greatly affected the results of the SNR in the EU method, it did not greatly influence the results of the NEMA method. The SNR in the EU method in which the size of area of interest was set to 50% and the SNR in the proposed method in which the SNR was estimated in the GMM were similar.

**Conclusion**
In this study, the SNR was calculated by three kinds of methods: the proposed method, the NEMA method, the EU method. The SNR calculated in the GMM by the proposed method was equivalent to the value of the EU method in which the area of interest was set to 50% of the phantom areas. Since the EU method uses the standard deviation of the signal level as a noise value, it may be influenced by signal nonuniformity due to the magnetic field heterogeneity or shading including artifact. Caution must be exercised so that the marginal region is not included in the area of interest because MR image has larger signal nonuniformity in the marginal region than the center of the phantom. The proposed method does not have to set the area of interest, and the probability density function estimated in the GMM can be used for estimation of the Gaussian distribution at the center and marginal region separately. Therefore, when the SNR was calculated using only the probability density function which estimated the center area, it is equivalent to the SNR of the EU method calculated in the small area of interest.

The SNR calculated by the NEMA method showed higher value than the SNR calculated by other methods. When each signal level was compared to each noise level, the signal levels were almost same regardless of calculation methods. However, the noise level measured by the NEMA method is the lowest, which is a factor for increasing SNR. Although the noise level by the NEMA method was calculated by subtracting the images to eliminate the signal nonuniformity due to the magnetic field heterogeneity, it is lower than that by other methods because it does not include a structure noise.\(^7\) For simulation images, a structure noise was not added and therefore same SNRs were calculated by all the methods.

Our proposed method can calculate SNR by only one imaging, and does not depend on the size of area of interest. Therefore this method has high reproducibility. In addition, in this method, evaluation by taking into account the structure noise is possible and can provide the results which are close to evaluation done by human. It seems to be difficult to use our method for the calculation method for clinical MR images. However, it is thought that our proposed method has adequate usefulness as easy calculation method for the purpose of performance evaluation or daily inspection of devices.

We developed a new SNR calculation method for MR images and examined its usability by comparing between the verification of the precision in simulation images and the existing methods for phantom images. As a result, this new proposed method has the precision that is equivalent to the existing methods, and its validity was proved. In addition, since SNR by this method can be calculated by only one imaging and has high reproducibility, it can be concluded that the proposed method is a useful calculation method.

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