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Integer Quantization: A Hidden Source of Bias in MRI SNR and RF Coil QA

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ABSTRACT

Purpose: To evaluate integer quantization as a source of bias in MRI SNR and RF coil QA measurements.

Methods: Analytical correction factors were derived for Mean, RMS, SD, and NEMA subtraction noise estimates under rounding and truncation. The corrections were tested using numerical integration, Monte Carlo simulation, and phantom scans on GE, Siemens, and Philips 1.5 T systems with 1-, 8-, 18-, and 21-channel coils.

Results: Integer quantization produced large noise-estimation errors when background noise was small, with uncorrected errors of approximately 5–60%. Correction factors reduced errors to below 1% over most of the tested range for Mean, RMS, and SD estimates. NEMA subtraction remained highly variable. Vendor behavior differed: Siemens and newer GE software used truncation, older GE software used rounding, and Philips used truncation with possible DICOM rescaling.

Conclusion: Integer quantization can substantially bias SNR measurements in high-SNR MRI QA. Correction factors are simple to apply and improve the accuracy and reproducibility of RF coil QA measurements.

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INTRODUCTION

Integer storage can bias MRI noise and SNR measurements by 5–60% when background noise is small. This is a common problem in high-SNR multichannel phased array coil testing. This work looks at how to identify the quantization method used by each MRI vendor and how to correct for the bias with four commonly used noise estimation methods. Simple correction terms are presented that largely remove this bias, both in theory and in practice. However, no correction method removed the large instability observed using the NEMA subtraction method.

METHODS AND MATERIALS

Analytical expressions were derived to quantify quantization-induced bias in noise estimates obtained using the standard deviation, mean, root-mean-square and NEMA subtraction methods.

Numerical integration of Rayleigh and chi probability density functions was performed across a wide range of noise levels and coil channel counts to derive correction factors.

These factors were validated using Monte Carlo simulations and experimentally with phantom scans acquired on GE, Siemens, and Philips 1.5 T systems using 1-, 8-, 18-, and 21-channel RF coils under varying reconstruction scaling factors (Siemens) and slice thicknesses (GE and Philips).

Common acquisition parameters:
SE, TR/TE = 200/20, BW = 244 Hz/px, 256×256, 1 NEX, 2 dynamics for NEMA subtraction; all channel images saved; reconstruction filters disabled when possible. NEMA subtraction never used for the channel data.

Testing on Siemens Aera 1.5T Software E11
Siemens Body 18 coil with large cylindrical phantom, FOV=50 cm, Slice thickness = 1.2 mm, 18 coronal scans with FFT scaling factors ranging from 0.4 to 5.0

Testing on GE HDx 1.5T Software 11.1
Split top head coil with ACR phantom, FOV=40 cm, 13 axial scans with slice thickness ranging from 1 to 12 mm.

Testing on GE Voyager 1.5T Software 29.1
GE 21-channel HNU coil with a 29 cm long x 16 cm diameter rounded cylinder phantom filled with acrylamide gel (JM Specialty parts), FOV=50 cm, 10 coronal scans with slice thickness ranging from 1 to 12 mm.

Testing on Philips Ambition 1.5T – Software 12.2.0
Philips 16-channel knee coil with 12 cm disk. Only 8 of the 16 channels were used for this testing. FOV=36 cm, 13 axial scans with slice thicknesses ranging from 1.5 to 10 mm. Reconstruction controls set as listed in Table 1.

Field	Setting
Clear Uniformity Optimization	Constant Noise (both fields)
Synco enable bg offset red.	No
Synco enable hom. Corr.	No
Synco enable RCA reduction	No
Uniform Scaling	Yes
Shutter Type	None
GeoCorrection	None
Fixed Scale Type	None

Table 1. Fields to be set in the Philips control parameters Recon Tab.

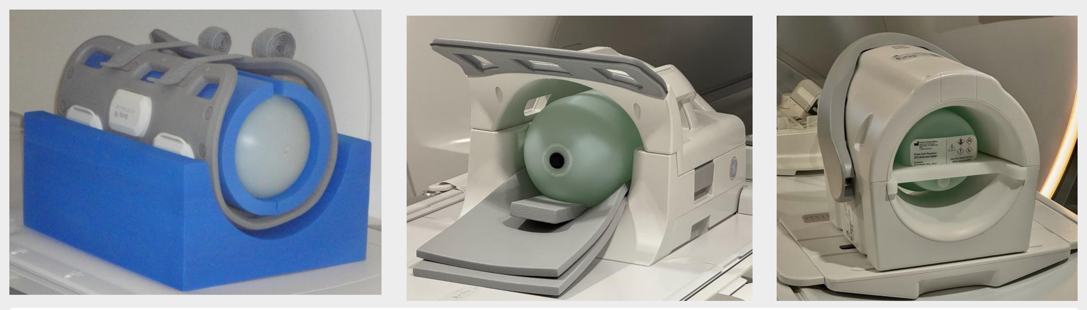

Figure 1. Coils and phantoms used for Siemens Aera, GE Voyager and Philips Ambition. (Not shown is ACR phantom in GE split top head coil)

RESULTS

Method	Uncorrected	Corrected for Truncation	Corrected for Rounding
Mean	$\hat{\mu}/k_{mean}$	$(\hat{\mu}+\Delta/2)/k_{mean}$	$\hat{\mu}/k_{mean}$
Variance	$\hat{\sigma}/\,k_{SD}$	$\sqrt{\hat{\sigma}^2-\Delta^2/12}\,/\,k_{SD}$	$\sqrt{\hat{\sigma}^2-\Delta^2/12}\,/\,k_{SD}$
RMS	$\sqrt{\mu_{\hat{P}^2}}\,/\sqrt{2n}$	$\sqrt{\mu_{\hat{P}^2}+\Delta\mu_{\hat{P}}+\Delta^2/6}\,/\sqrt{2n}$	$\sqrt{\mu_{\hat{P}^2}-\Delta^2/12}\,/\sqrt{2n}$
NEMA	$\sqrt{\sigma_{\hat{D}^2}}\,/\sqrt{2n}$	$\sqrt{\sigma_{\hat{D}^2}-\Delta^2/6}\,/\sqrt{2n}$	$\sqrt{\sigma_{\hat{D}^2}-\Delta^2/6}\,/\sqrt{2n}$

Table 2. Derived correction methods for estimating σ. $\hat{P}$: Measured pixel values. $\hat{D}$: Measured NEMA difference pixel values. Δ: Quantization step size. Δ is almost always 1.0 for every MRI vendor except Philips. When Philips uses DICOM rescaling, Δ is the slope of the rescaling.

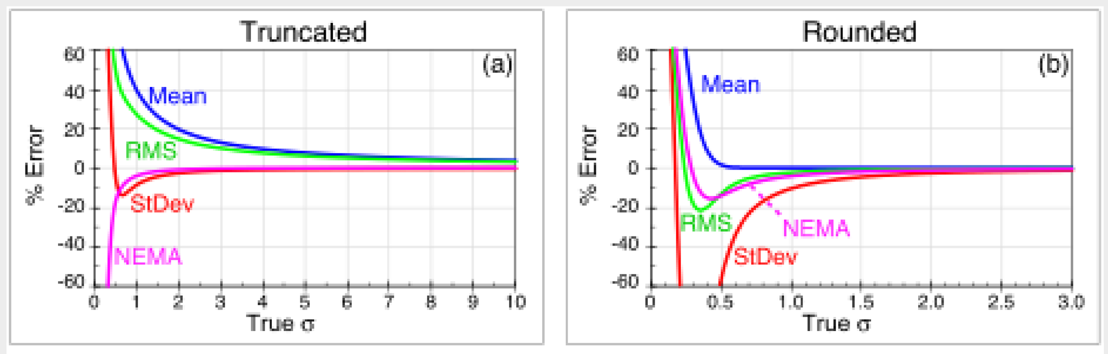

Figure 2. Percent error in estimating true σ when (a) truncation or (b) rounding is used to convert the floating-point data to integer.

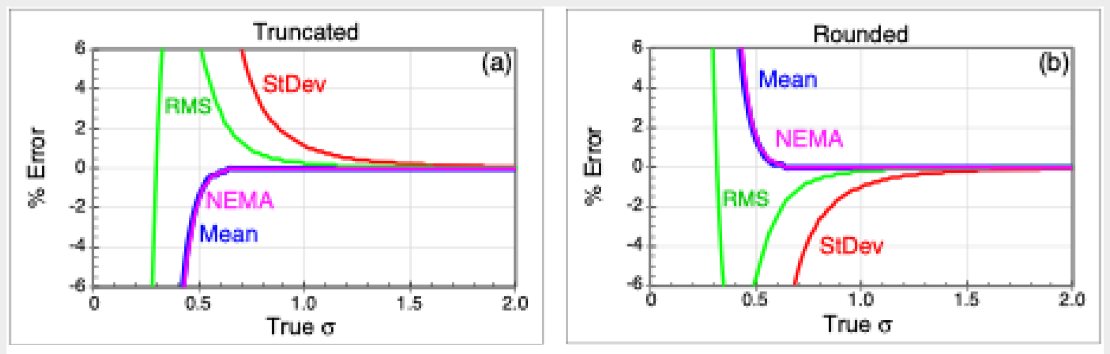

Figure 3. Remaining percent error in estimating true σ after applying the correction factors from Table 1. Note the significant change in scale from Figure 2 to Figure 3.

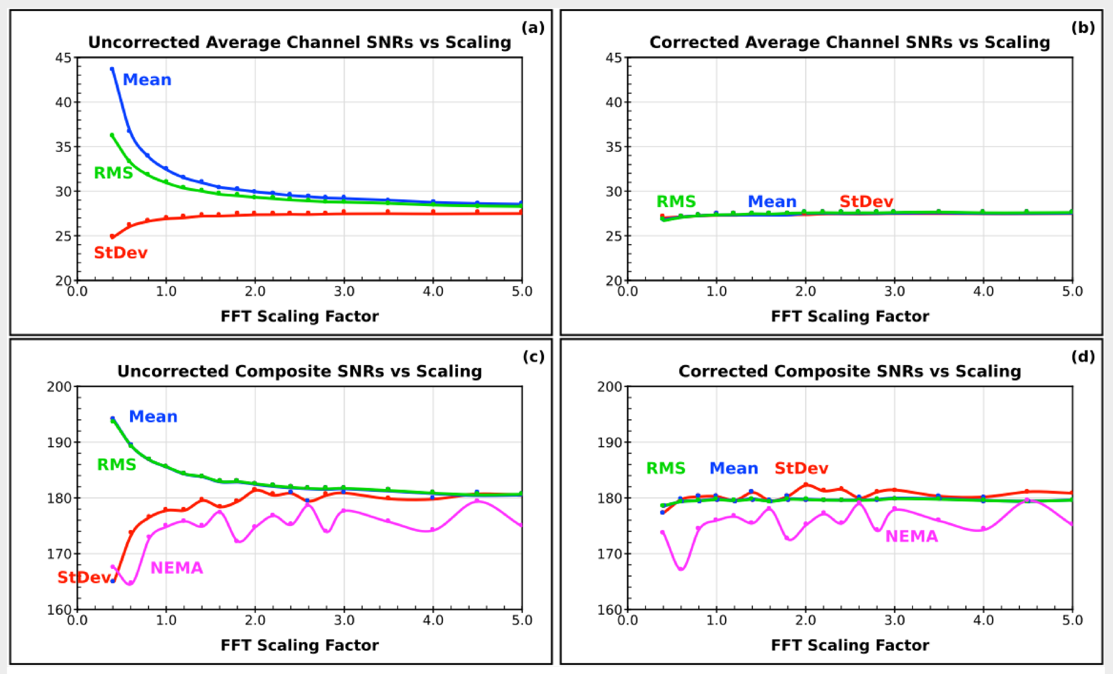

Figure 4. Siemens Body 18 results. Upper plots show estimates of σ averaged over 18 channels, (a) without correction and (b) with correction. Lower plots show the corresponding SNR values of the composite images (c) without correction and (d) with correction. NEMA subtraction showed excessive fluctuation.

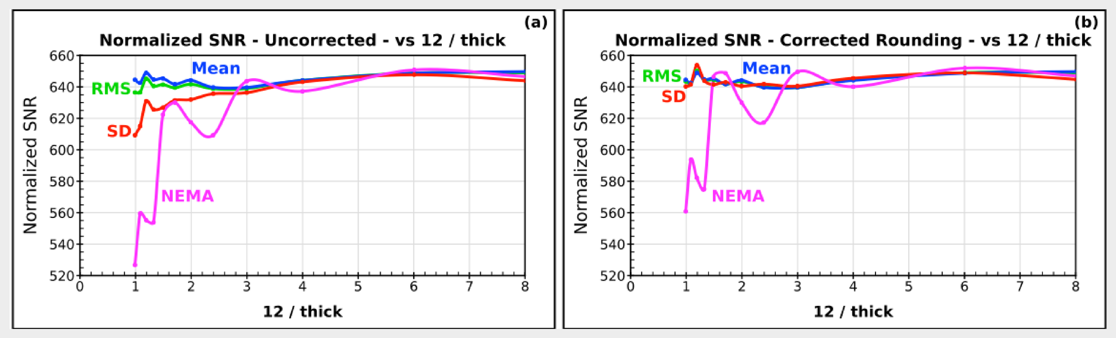

Figure 5. GE HDx Head coil results. This software uses rounding. (a) SNR values without correction. (b) After correction. After correction the SD and RMS results were nearly identical to the Mean results. NEMA subtraction showed excessive fluctuation.

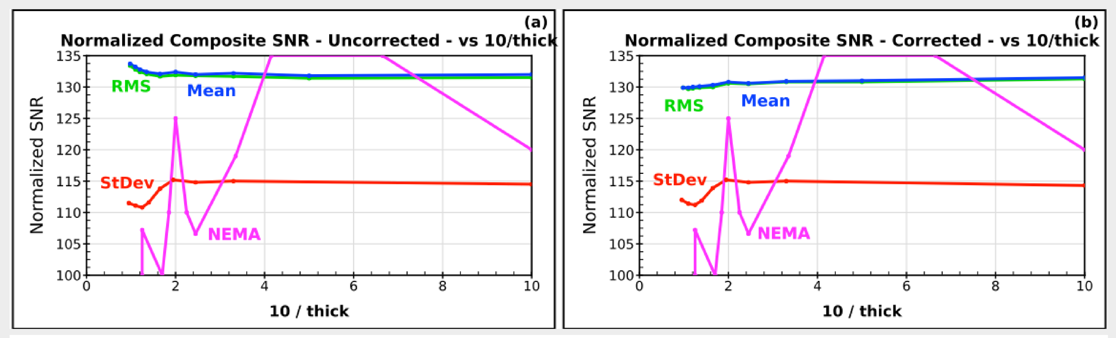

Figure 6. GE Voyager HNU results. This software uses truncation. (a) SNR values without correction. (b) After correction. The Mean and RMS methods are nearly identical. The SD method showed more overall variation. Even after correction, SD differs from the Mean and RMS. NEMA subtraction showed excessive fluctuation and is effectively useless. Corrections had a larger effect on channel data (not shown).

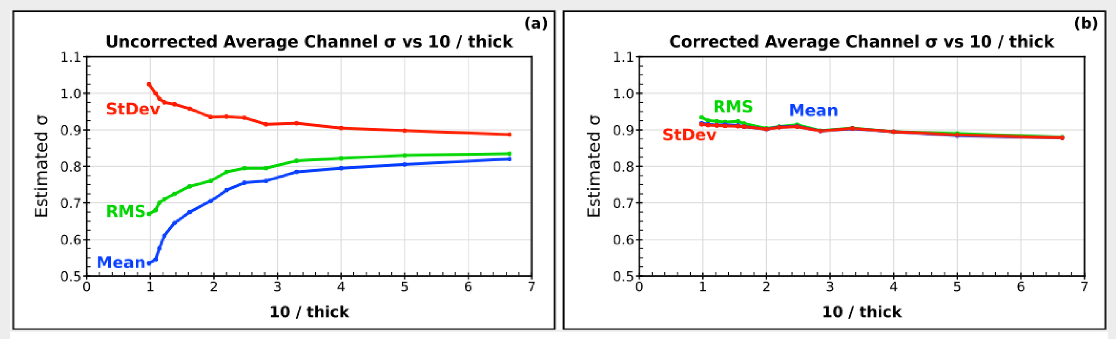

Figure 7. Philips Ambition Knee results. This software uses truncation. (a) σ estimates obtained without correction. (b) After correction. NEMA subtraction was not used on the Philips scanner.

DISCUSSION

Integer quantization introduces a systematic error when low-noise floating-point MR images are stored as integer pixel values. The error is largest when the noise standard deviation is comparable to the quantization step. The direction and magnitude of the bias depend on the quantization method and the noise estimator used.

The mean and RMS noise estimators were the most stable across vendors and acquisition conditions. The SD estimator was more sensitive to quantization, although correction substantially improved its agreement with the Mean and RMS methods.

The NEMA subtraction method performed poorly in all cases, apparently because small differences between repeated acquisitions dominated the measurement, even when a non-liquid phantom was used.

These results show that a single uncorrected SNR workflow can produce vendor- and software-dependent bias even when the underlying coil performance is unchanged.

CONCLUSIONS

Integer conversion of MR images is an under-recognized source of bias in SNR and RF coil QA measurements.

Quantization bias can be large when background noise is small, producing uncorrected errors of approximately 5–60% in the tested conditions.

Simple correction factors based on the quantization model substantially reduce this bias for Mean, RMS, SD and NEMA subtraction method based noise estimates.

The Mean-based estimator was the most robust method across the tested vendors, coils, and noise levels and should be the method of choice for RF coil QA.

NEMA subtraction was highly variable in these QA datasets and should be used cautiously, if at all.

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