Evaluation of SNR/Resolution Tradeoffs Using the Theoretical Information Content

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Introduction: In magnetic resonance imaging a tradeoff exists between resolution and the signal to noise ratio (SNR). With any imaging protocol, different fractions of the available scan time could be used to acquire data at higher spatial frequencies (achieving higher resolution) and to perform signal averaging (obtaining greater SNR). A potential way to establish the optimal balance between resolution and SNR is to determine the solution which provides the maximum information content. First defined by Shannon (1) in the context of communication theory, the theoretical information content has since been used as a measure of image quality in the fields of photography and medical imaging (CT and MRI) (2,3). In this study, the information content of a variety of MR images, which corresponded to different SNR/resolution tradeoffs for a range of scan durations, was determined.

Methods: Three dimensional images of in-situ fixed mouse brains were acquired on a 7-T Varian *Inova* scanner (Varian Inc., Palo Alto, CA), using a fast spin-echo pulse sequence (4). Sequence parameters included: TR=325 ms, ETL=6, ESP=8 ms, TE_{eff}=32 ms, FOV=14x14x25mm, and 4 averages. Images were acquired with 32 µm isotropic resolution and had an average SNR of 16. The total imaging time was approximately 12 hours. These high resolution MR images served as a reference data set. By adding Gaussian white noise (in k-space) and choosing reduced k-space volumes, the reference images were degraded to simulate shorter scan times and different SNR/resolution tradeoffs. In particular, 7 different scan durations ranging from 45 minutes to 42 seconds (decreasing by factors of 2) were simulated. For each of these durations, several different combinations of SNR and resolution were generated. A selection of tradeoff images is shown in Figure 1.

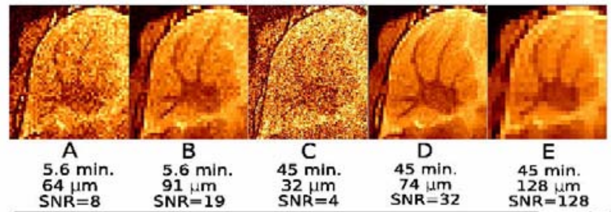

Figure 1: Examples of tradeoff images. A sagittal section through the cerebellum is shown.

The information content (in bits) of each tradeoff was evaluated according to the equation provided by Fuderer (3), who first applied information theory to the assessment of MR image quality:

$$I = \frac{1}{2}\sum_{k_x}\sum_{k_y}\log_2 \frac{P_s(k_x,k_y)+P_N}{P_N} \quad [1]$$

In this expression, $P_S(k_x,k_y)$ refers to the signal power (i.e. the square modulus of the signal) at spatial frequency position (k_x,k_y) and P_N refers to the noise power. The dependence of the noise power on position is omitted, as the noise is assumed to be white. The noise power includes both physical and instrumental noise, as well as the noise that was added to k-space to simulate the various tradeoffs.

Results & Discussion: Plots of the information content of each of the analyzed tradeoffs are shown in Figure 2. Figure 2a is a plot of information *vs.* SNR, while figure 2b is a plot of information *vs.* resolution. Both plots include a family of 7 curves, each of which corresponds to a different scan duration. The data points along each curve represent simulated tradeoffs, which have different values of SNR and resolution, since different fractions of the fixed imaging time were spent acquiring additional k-space lines and performing signal averages. Two bars on each curve mark the boundaries between which the information content is within 95% of the maximum value.

A number of important observations can be made from the data shown in Figure 2. Not surprisingly, as scan time increases, so does information content. Interestingly, however, Figure 2a shows that for a given SNR, the information content obtained relative to the maximum value, is virtually independent of scan time. For example, all tradeoffs with an SNR of approximately 11 (Figure 2a, dashed line), obtained more than 95% of the maximum information content. This is an important result, suggesting that the signal to noise ratio is the decisive parameter for optimizing information. As indicated by Figure 2b, the resolution at which the critical SNR value is obtained (dashed line) depends on the scan duration: as scan time increases, the desired SNR is achieved at a finer resolution.

The 95% boundaries indicated in Figure 2a occupy a relatively wide range of SNR values. With a 5.6 minute scan duration, for instance, any SNR value between 6 and 22 falls within 95% of the maximum. The fact that a more than three-fold increase in SNR (and an increase in resolution from 57 – 96µm) is accompanied by only a 5% change in information content, brings the strength of this metric into question. In spite of the appreciable visible difference between them, tradeoff images A and B in Figure 1 differ in information content by less than 0.2%. This suggests that, for the tradeoffs analyzed in this study, the theoretical information content may not be a sufficient description of image quality.

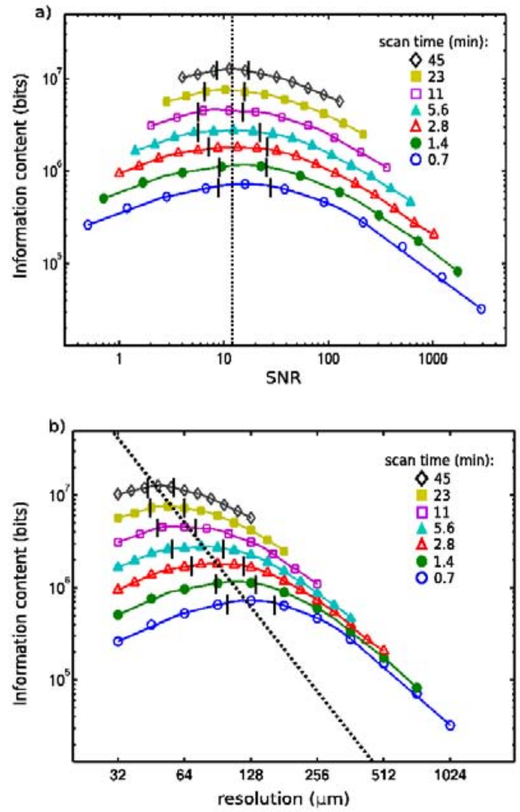

Figure 2: Information content vs. SNR (a) and resolution (b). Lines connecting the data points were drawn using cubic spline interpolation

Conclusion:
In this study, we have used the theoretical information content to establish the optimal tradeoff between SNR and resolution for a fixed imaging time. Results show that with an SNR of 11, the information content obtained is always within 95% of the maximum value, regardless of the total imaging time. This value may be used as a general standard in MR imaging. However, considering the low specificity that was observed with this metric, any interpretation of image quality based solely on the information content should be made with caution.

References:
(1) Shannon, CE. *Proceedings of the IRE*, vol. 37, no.1, Jan. 1949.
(2) Wagner, R, Brown, D, Pastel, M. *Med. Phys.*, vol. 6, no. 2, Mar. 1979.
(3) Fuderer, M. *IEEE Transactions on Medical Imaging*, vol. 7, no. 4, Dec. 1988.
(4) Henkelman, RM *et al. Proc Intl Soc Mag Reson Med*, abstract #2010, 2006.