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Determination of Signal-to-Noise Ratio (SNR) in Diagnostic Magnetic Resonance Images

NEMA

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MS 1

DETERMINATION OF SIGNAL-TO-NOISE RATIO (SNR) IN DIAGNOSTIC MAGNETIC RESONANCE IMAGES

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Foreword

This Standards Publication describes a method for evaluating the signal-to-noise ratio (SNR) performance of a diagnostic magnetic resonance imaging system. The test has been designed such that it may be performed on all clinical magnetic resonance (MR) systems, requiring a minimal level of sophistication in the equipment or data reduction techniques.

This procedure is defined in sufficient detail to ensure meaningful and repeatable results when executed with a set of hardware and scan parameters satisfying the requirements described herein. However, the procedure has also been specifically structured so that it can be adapted for use on various MR systems, for example by using custom phantoms which are of appropriate dimensions and loading characteristics for the system of interest. This flexibility implies that results acquired on different types of MR systems may not be directly comparable. The purpose of the procedure is to provide a standard means for measuring and reporting image SNR, which can be very useful for evaluating performance impacts of system changes or in demonstrating effectiveness for FDA applications.

The major feature of this testing method is that the signal-to-noise ratio performance of the system is evaluated in an image that is generated using a standard clinical scan procedure. The procedure is intended to measure thermal and other broadband, non-structured noise, and specifically does not address low frequency variations in an image or artifacts as defined herein.

It should be noted that since the procedure involves subtraction of two images, it can be very sensitive to system instabilities that occur during the data acquisition process. If results are highly variable, it may be advisable to perform additional image analysis (not described in this document) to determine if this is due to system instability or genuinely poor SNR.

In the preparation of this Standards Publication, input of users and other interested parties has been sought and evaluated. Inquiries, comments, and proposed or recommended revisions should be submitted to the concerned NEMA product subdivision by contacting the:

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Rationale

Image SNR is a parameter that relates to clinical usefulness of MR images and also is a sensitive measure of hardware performance. Experience has shown that variations in system calibration, gain, coil tuning, RF shielding, or other similar parameters are usually demonstrated by a corresponding change in image SNR. Thus, image SNR, along with several other key parameters such as slice thickness and geometric distortion, provides a good index of system image quality performance.

Scope

This document defines test methods for measuring the signal-to-noise ratio performance of diagnostic magnetic resonance imaging systems under a specific set of conditions, using head and body coils and performing proton imaging. This document does not address the use of surface coils, chemical shift imaging or spectroscopy.

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DETERMINATION OF SIGNAL-TO-NOISE RATIO (SNR) IN DIAGNOSTIC MAGNETIC RESONANCE IMAGES

Section 1
DEFINITIONS

1.1 DATA ACQUISITION PARAMETERS

The following data acquisition parameters must accompany the statement of the signal-to-noise ratio number:

Parameter	Dimensions
Phantom filler T_1	milliseconds
Phantom filler T_2	milliseconds
Pixel bandwidth	hertz per pixel
Voxel dimensions	each dimensions in millimeters
Receive channel 3dB bandwidth	kilohertz
TR; sequence repetition time	milliseconds
TE; echo delay time	milliseconds
Number of signals averaged (NSA)	–
Data acquisition matrix size	–

1.2 MEASUREMENT REGION OF INTEREST (MROI)

A centered, regular geometric area enclosing at least 75% (area) of the image of the signal producing volume of the phantom.

1.3 IMAGE ARTIFACT

An image anomaly, excluding image noise as defined in 1.5, which is not representative of the structure or chemistry in the object being scanned; or, an anomaly derived from the structure or chemistry of the object being scanned but which appears in the image at other than its expected location.

1.4 IMAGE SIGNAL

The mean pixel value within the MROI (minus the baseline pixel offset, if any) in the original, unsubtracted image.

1.5 IMAGE NOISE

The random variations in pixel intensity in the MROI in a difference image calculated from a sequential pair of scans. It is given by the standard deviation of the pixel values in the MROI divided by the square root of two.

1.6 IMAGE SIGNAL-TO-NOISE RATIO

This is a single number that results from dividing the image signal (1.4) by the image noise (1.5). Statement of the signal-to-noise ratio must include the information listed in Section 1.1.

1.7 VOXEL DIMENSIONS

This parameter is composed of three elements:

Slice thickness – operator selected slice thickness.

Pixel horizontal dimension – the field of view in the horizontal direction divided by the number of data sampling points in the horizontal axis. This corresponds to the horizontal dimension of the data acquisition matrix.

Pixel vertical dimension – the field of view in the vertical direction divided by the number of data sampling points in the vertical axis. This corresponds to the vertical dimension of the data acquisition matrix.

1.8 MAXIMUM SELECTABLE VOLUME

For a given scan orientation (i.e., transverse, sagittal, coronal), the volume enclosed by the maximum selectable fields of view and the planes of maximum selectable slice offset from isocenter.

1.9 SPECIFICATION VOLUME

The imaging volume over which a manufacturer guarantees image performance specifications will hold. Images or portions of images outside this volume will not necessarily meet performance specifications, but can still be useful for diagnostic purposes and require subjective judgment on the part of the diagnosing physician. For head scans, the specification volume must enclose, as a minimum, a ten centimeter diameter spherical volume (dsv) centered in the RF head coil, and similarly for body scans it must enclose, as a minimum, a twenty centimeter dsv centered in the RF body coil.

1.10 SPECIFICATION AREA

The specification area is the intersection of the specification volume and the image plane.

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Section 2
METHODS OF MEASUREMENT

2.1 TEST HARDWARE

2.1.1 Size of the Signal Producing Volume

The size of the signal producing volume is determined by the thickness of the slice being imaged (per the protocol in 2.2) and the cross-sectional area resulting from the intersection of the image plane and the phantom. The size of this cross-sectional area must meet the following requirements:

Head scans: in the image plane the phantom shall enclose, as a minimum, a ten centimeter diameter circle or 85% of the specification area, whichever is larger.

Body scans: in the image plane the phantom shall enclose, as a minimum, a twenty centimeter diameter circle or 85% of the specification area, whichever is larger.

2.1.2 RF Coil Loading Characteristics

In order to approximate the image noise performance that would be typically encountered in a clinical situation, the RF receive coil of interest (i.e., either head or body coil) must be electrically loaded. Loading may be accomplished by phantoms or other reproducible means. When loaded, the following electrical parameters must be the same as when a 50 to 90 kg human is positioned for a scan (within the stated tolerances):

Coil 3 dB bandwidth: $\pm 15\%$
Coil impedance: $\pm 20\%$ magnitude, $\pm 20^{\circ}$ phase
Coil center frequency shift: $\pm 1\%$ of center frequency

2.1.3 NMR Characteristics of the Signal Producing Volume

$T_1 < 1200$ milliseconds (at operating field strength)
$T_2 > 50$ milliseconds (at operating field strength)
Spin density = density of $H_2O \pm 20\%$

2.2 SCAN CONDITIONS

Image signal-to-noise ratio data shall be acquired using a typical clinical scan sequence and reconstruction process, which has not been altered in any fashion to affect the SNR results. In addition, the following scan conditions shall be used to acquire the data:

1. The phantom shall be centered in the RF receive coil;
2. RF receive coil shall be electrically loaded per 2.1.2;
3. Room and phantom temperature shall be 22 $\pm 4^{\circ}$C;
4. TR $\leq 5 \times T_1$ of the filler material in the signal producing volume;
5. TE within the clinically selectable range;
6. Single, transverse slice centered at isocenter;
7. The selected field of view shall not exceed 110% of the largest linear dimension of the RF coil in the image plane;
8. Spin echo pulse sequence (first echo);
9. Slice thickness ≤ 10 mm.

2.3 MEASUREMENT PROCEDURE

System image uniformity shall be determined by sequentially executing the following procedure.

2.3.1 Center the signal producing volume of the phantom (head or body as appropriate) in the RF receive coil and load the coil per 2.1.2.

2.3.2 Perform the standard clinical pre-scan calibration procedure as recommended by the system manufacturer.

2.3.3 Execute two scans sequentially with less than 5 minutes elapsed time from the end of the first scan to the beginning of the second (images number 1 and number 2). No system adjustment or calibration shall be performed between scans.

IMPORTANT: Some of the following steps involve statistical analysis of the images. This analysis must be performed on images which have been processed by the system's typical diagnostic clinical reconstruction algorithm, but prior to any further modifications for display purposes (e.g., interpolation, filtering).

2.3.4 Determine the mean pixel value within the MROI on image number 1. The resulting number (minus the baseline pixel offset value, if any) will be called "SIGNAL", S.

2.3.5 Calculate a pixel-by-pixel difference image (hereafter referred to as image 3) as follows:

[image 3] = [image 1] – [image 2].

IMPORTANT: The image subtraction process must avoid errors which could result from the generation of pixel values which exceed the maximum/ minimum pixel values allowed on the particular scanning system.

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2.3.6 Determine the standard deviation within the MROI on image 3. The resulting number will be called the "standard deviation", SD.

2.3.7 Calculate the signal-to-noise ratio (SNR) as follows:

$$SNR = \frac{S}{(SD) / (\sqrt{2})}$$

IMPORTANT: Statement or quotation of this SNR must be accompanied by the scan data acquisition parameters (see 1.1).

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(Standardization Policies and Procedures, p. 2)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the standards publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 9)

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National Electrical Manufacturers Association Standards are of two classes:

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(Standardization Policies and Procedures, pp. 8 & 17)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

(Standardization Policies and Procedures, pp. 8 & 17)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment, and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 8 & 17)

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Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

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