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

NEMA

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NEMA MS 1

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

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

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Preamble

This is one of a series of test standards developed by the medical diagnostic industry for the measurement of performance parameters governing the image quality of magnetic resonance imaging systems. These test standards are intended for the use of equipment manufacturers, prospective purchasers, and users alike.

Manufacturers are permitted to use these standards for the determination of system performance specifications. This standardization of performance specifications is of benefit to the prospective equipment purchaser, and the parameters supplied with each NEMA measurement serve as a guide to those factors that can influence the measurement. These standards can also serve as reference procedures for acceptance testing and periodic quality assurance.

It must be recognized, however, that not all test standards lend themselves to measurement at the installation site. Some test standards require instrumentation better suited to factory measurements, while others require the facilities of an instrumentation laboratory to assure stable test conditions necessary for reliable measurements.

The NEMA test procedures are carried out using the normal clinical operating mode of the system. For example, standard calibration procedures, standard clinical sequences, and standard reconstruction processes shall be used. No modifications to alter test results shall be used unless otherwise specified in these standards.

The NEMA Magnetic Resonance subdivision has identified a set of key magnetic resonance image quality parameters. This Standards Publication describes the measurement of one of these parameters.

Equivalence

It is intended and expected that manufacturers or others who claim compliance with these NEMA standard test procedures for the determination of image quality parameters shall have carried out the tests in accordance with the procedures specified in the published standards.

In those cases where it is impossible or impractical to follow the literal prescription of a NEMA test procedure, a complete description of any deviation from the published procedure must be included with any measurement claimed to be equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by each reader.

Uncertainty of the Measurements

The measurement uncertainty of the image quality parameter determined using this standard is to be reported, together with the value of the parameter. Justification for the claimed uncertainty limits shall also be provided by a listing and discussion of sources and magnitudes of error.

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Foreword

This procedure defines two methods to measure image signal-to-noise ratio (SNR). The major feature of the first method is that the SNR performance of the system is evaluated using a standard clinical scan procedure. However, it should be noted that since this method involves the subtraction of two images, it can be very sensitive to system instabilities that may occur during the data acquisition process. If results are highly variable, it is advisable to perform the alternative method of noise measurement. This technique has been designed to be less susceptible to system instabilities and can be used to determine if any variability in the SNR is due to system instability or genuinely poor SNR. Both procedures are intended to measure thermal and other broadband, non-structured noise, and specifically do not address low frequency variations in an image or artifacts as defined herein.

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 magnetic resonance images and also is a sensitive measure of hardware performance. Experience has shown that variations in systems calibration, gain, coil tuning, radio frequency shielding, or other similar parameters are usually demonstrated by a corresponding change in image SNR. This 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 MEASUREMENT REGION OF INTEREST (MROI)

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

1.2 IMAGE ARTIFACT

An image anomaly, excluding image noise as defined in 1.4, which is not representative of the structure or chemistry of 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.

1.3 IMAGE SIGNAL

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

1.4 IMAGE NOISE

The random variations in pixel intensity in the MROI.

1.5 IMAGE SIGNAL-TO-NOISE RATIO

This is a single number that results from dividing the image signal (1.4) by an estimate of the image noise.

1.6 VOXEL DIMENSIONS

This parameter is composed of three elements:

a. Slice thickness—operator selected slice thickness.

b. 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.

c. 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 acquisition matrix.

1.7 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.

1.8 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 judgement on the part of the diagnosing physician. For head scans, the specification volume must enclose, as a minimum, a 10 centimeter diameter spherical volume (dsv) centered in the RF head coil, and similarly for body scans it must enclose, as a minimum, a 20 centimeter dsv centered in the RF body coil.

1.9 SPECIFICATION AREA

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

1.10 MAGNITUDE IMAGE

The magnitude image is formed by taking the magnitude of each complex pixel.

1.11 REAL IMAGE

After reconstruction, the image pixels are vectors with real and imaginary parts. A phase correction is applied to the image in an attempt to rotate the noise-free signal to the real axis. The positive and negative real components of each pixel form the real image.

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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:

a. 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.

b. 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):

a. Coil 3 dB bandwidth: ± 15%

b. Coil impedance: ± 20% magnitude, ± 20° phase

c. Coil center frequency Shift: ± 1% of center frequency

2.1.3 Nuclear Magnetic Resonance (NMR) Characteristics of the Signal Producing Volume

a. T_1<1200 milliseconds (at operating field strength)

b. T_2 > 50 milliseconds (at operating field strength)

c. Spin density = density of H_20 ± 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:

a. The phantom shall be centered in the RF receive coil.

b. RF receive coil shall be electrically loaded per 2.1.2.

c. Room and phantom temperature shall be 22 ± 4°C.

d. Sequence repetition time (TR) ≤ 5 × T_1 of the filler material in the signal-producing volume.

e. Echo Delay Time (TE) shall be within the clinically selectable range.

f. Single, transverse slice shall be centered at isocenter.

g. The selected field of view shall not exceed 110% of the largest linear dimension of the RF coil in the image plane.

h. Spin echo pulse sequence (first echo).

i. Slice thickness ≤ 10 mm.

2.3 MEASUREMENT PROCEDURE

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 standard diagnostic clinical reconstruction algorithm, but prior to any further optional modifications for display purposes (e.g., interpolation, filtering).

2.3.1 Image Signal Determination

Image signal shall be determined by executing the following procedure.

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a. 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.

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

c. Perform the scan to obtain image 1.

d. Determine the mean pixel value within the (MROI). The resulting number (minus the baseline pixel offset value, if any) is called the "signal," S.

2.3.2 Procedures to Evaluate Image Noise

Either of two procedures shall be permitted to evaluate image noise. The first method requires the subtraction of two signal-containing images. The second method requires the generation of an image with no NMR signal. (The second method evaluates the noise directly from an image having no coherent signal.) In either case, the second scan shall be performed with less than 5 minutes elapsed time from the end of the first scan to the beginning of the second.

2.3.2.1 Method 1

The second image (image 2) is acquired under precisely the same conditions as the first. No system adjustment or calibration shall be performed between scans. 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.

Determine the standard deviation SD of the pixel values within the MROI on image 3.

The method of calculating the standard deviation can affect the result. Temporal instability of the MR imager can give rise to artifacts in the subtracted image which increase the standard deviation. These artifacts normally have low spatial frequency, and their effect on the calculation of the standard deviation can be sharply reduced by evaluating the successive differences between adjacent points.

$$SD = \left[\frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i-1} (V(i,j+1)-V(i,j))^2}{2\sum_{i=1}^{n}(m_i-1)} \right]^{\frac{1}{2}}$$

Equation 1

Where:

n = number of rows in the ROI
m_i = number of columns in each row
V(i,j) = is the pixel value in image 3

Temporal stability can be evaluated by comparison of the standard deviation calculated this way with that calculated by the usual formula:

$$SD = \left[\frac{\sum_{i=1}^{n} \sum_{j=1}^{m_i} (V(i,j)-\bar{V})^2}{\sum_{i=1}^{n} m_i} \right]^{\frac{1}{2}}$$

Equation 2

Where:

$\bar{V}$ = average pixel value in image 3 (or the noise image in method 2)

Calculate the image noise as follows:

$$\text{image noise} = \frac{SD}{\sqrt{2}}$$

2.3.2.2 Method 2

A noise scan image is acquired with the phantom in its original position and with no RF excitation. This permits a reduced scan time for the noise image because TR can be reduced to a minimum without any effect on the image.

Ensure that the output from the transmitter is such that no NMR signal is generated upon execution of the noise scan. It shall be permitted to turn off the RF amplifer or otherwise suppress the RF excitation.

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Ensure that the system receiver attenuation (or gain control) and any scaling of the image reconstruction are identical to that of the first scan.

Except for TR, the noise image is acquired under the same conditions as image 1. No system adjustment or calibration shall be performed between scans.

Determine the standard deviation, SD, of the pixel values within the MROI on the noise image using equation 2.

If a magnitude image is evaluated, the image noise is:

$$\text{image noise} = SD/0.66$$

The factor of 0.66 i.e., $\sqrt{(4-\pi)/2}$ accounts for the Rayleigh distribution of the noise in the magnitude noise image.

If a real image is evaluated, the image noise is:

$$\text{image noise} = SD$$

2.3.3 The SNR is determined by:

$$SNR = S/(\text{image noise})$$

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Section 3
RESULTS

3.1 REPORTING OF RESULTS

3.1.1 Provide the resulting SNR

3.1.2 List the following data acquisition parameters:

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

3.1.3 List the reconstruction parameters selected in 2.3.

3.1.4 Provide the following additional data:

a. Method used to evaluate noise (method 1 or method 2)

b. If method 1, equation used to calculate standard deviation (equation 1 or equation 2).

c. Specification area—size and shape

d. Cross-sectional area of phantom—size and shape

e. MROI— size and shape

f. The Method of conformance to the RF loading characteristic stated in 2.1.2.

3.1.5 List other relevant information that ensures repeatability.

3.1.6 List the potential sources of error.

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NEMA STANDARDIZIATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

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. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

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 received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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