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Determination of Image Uniformity in Diagnostic Magnetic Resonance Images

NEMA

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DETERMINATION OF IMAGE UNIFORMITY IN DIAGNOSTIC MAGNETIC RESONANCE IMAGES

Published by:

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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 Standard 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 safety 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 Standards Publication has been approved as NEMA Standard March 1, 1989.

Image uniformity refers to the ability of the MR imaging system to produce an identical signal response throughout the scanned volume when the object being imaged has homogeneous MR characteristics. It is quantified in terms of the deviation in the image signal intensity relative to the midrange pixel value. Some parameters contributing to the image nonuniformity are RF and magnetic field inhomogeneities, RF coil geometry and penetration, inadequacies in gradient pulse calibration or eddy current corrections, and spatial positioning of the phantom.

Analysis of uniformity requires the measurement of pixel variations (span) within the full region of interest that is typically occupied by clinical samples and not over the full available volume of the RF coil. The uniformity parameter allows for accurate assessment of the distribution of pixel intensities throughout such a region.

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

This Standard measures integral uniformity (see 1.4) to characterize the low spatial frequency nonuniformities typical of MR images.

Measurements are made over a volume that is representative of the region used for typical clinical studies.

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Scope

This document defines a test method for measuring image uniformity performance of diagnostic magnetic resonance imaging systems 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 UNIFORMITY IN DIAGNOSTIC MAGNETIC RESONANCE IMAGING

Section 1
DEFINITIONS

1.1 DATA ACQUISITION PARAMETERS

The following data acquisition parameters must accompany the statement of the image uniformity number:

Parameter	Dimensions
Phantom filler T1	milliseconds
Phantom filler T2	milliseconds
Phantom filler specific conductance (or phantom filler composition)	siemens per meter
Pixel Bandwidth	hertz per pixel
Voxel dimensions	each dimension 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 percent (area) of the image of the signal producing volume of the phantom.

1.3 IMAGE NONUNIFORMITY

The variations in pixel intensity within an image that are repeatable from scan to scan.

1.4 INTEGRAL UNIFORMITY

The maximum absolute deviation from a midrange pixel value (2.3.2, equation 3) expressed as a percentage.

1.5 VOXEL DIMENSIONS

This parameter is determined by three elements:

1. Slice thickness – operator selected slice thickness;
2. 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; and
3. 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.

1.6 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.

1.7 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 may 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 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.

1.8 SPECIFICATION AREA

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:

1. Head scans: in the image plane the phantom shall enclose, as a minimum, a 10 centimeter diameter circle or 85 percent of the specification area, whichever is larger.
2. Body scans: in the image plane, the phantom shall enclose, as a minimum, a 20 centimeter diameter circle or 85 percent of the specification area, whichever is larger.

2.1.2 MR Characteristics of the Signal Producing Volume

The MR characteristics of the Signal Producing Volume must meet the following requirements:

T1 < 1200 milliseconds (at operating field strength)
T2 > 50 milliseconds (at operating field strength)
Spin density = density of $H_2O \pm 20$ percent

2.2 SCAN CONDITIONS

Image uniformity data shall be acquired as a single slice scan at isocenter in each of the three orthogonal imaging planes. A typical diagnostic clinical scan sequence and reconstruction process shall be used. 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. Room and phantom temperature shall be 22±4°C;
3. $TR \leq 5 \times T_1$ of the filler material in the signal producing volume;
4. TE within the clinically selectable range;
5. The selected field of view shall not exceed 110 percent of the largest linear dimension of the RF coil in the image plane;
6. Spin echo pulse sequence (first echo); and
7. Slice thickness ≤10 mm.

2.3 MEASUREMENT PROCEDURE

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

1. Center the signal producing volume of the phantom in the RF receive coil;
2. Perform the standard clinical pre-scan calibration procedure as recommended by the system manufacturer; and
3. Execute the scan.

2.3.1 Pre-processing of the Image

To help minimize the effects of noise on the measurement, it shall be permitted to convolve the image I, with a nine point low-pass filter function $h(m_1,m_2)$. The filtered image is given by:

$$S(n_1,n_2) = \frac{1}{W} \sum_{m_1=-1}^{1} \sum_{m_2=-1}^{1} h(m_1,m_2)\, I(n_1-m_1,n_2-m_2)$$

where n_1, n_2 cover the range of the image.
The filter kernel is,

$$\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} = \begin{bmatrix} h(-1,-1) & h(-1,0) & h(-1,1) \\ h(0,-1) & h(0,0) & h(0,1) \\ h(1,-1) & h(1,0) & h(1,1) \end{bmatrix}$$

and represents the product of two raised cosines in the frequency domain. The weighting factor W is given by:

$$W = \sum_{m_1=-1}^{1} \sum_{m_2=-1}^{1} h(m_1,m_2)$$

and is used to normalize the dc response of the filter in the frequency domain to unity.* If the filter is not used, S = I.

*See NEMA NU 1, *Performance Measurements of Scintillation Cameras.*

2.3.2 Integral Uniformity

For pixels within the MROI, the maximum (S_{max}) and minimum (S_{min}) values are determined.

A span Δ and midrange value $\bar{S}$ are calculated as:

$$\Delta = \frac{S_{max}-S_{min}}{2} \qquad (1)$$

$$\bar{S} = \frac{S_{max}+S_{min}}{2} \qquad (2)$$

The ratio of Δ to $\bar{S}$ is multiplied by 100, and expressed as a plus/minus percentage integral uniformity. The relation for calculating integral uniformity (U) is:

$$U = \pm 100 \frac{\Delta}{\bar{S}} = \pm 100 \frac{S_{max}-S_{min}}{S_{max}+S_{min}} \qquad (3)$$

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Perfect integral uniformity is therefore represented by U = 0 percent.

Important: Statement or quotation of integral uniformity (U) must be accompanied by the scan data acquisition parameters (see 1.1) and a statement of whether or not the low pass filter of 2.3.1 was used. In addition, other relevant parameters needed to ensure repeatability shall be reported.

2.3.3 Gray-Scale Uniformity Map

It shall be permitted to provide a gray-scale-coded map of the image showing where, and by how much, departures in uniformity occur. Such a map is readily created by the following procedure:

1. Select a region of interest (ROI) on the center of the image that encloses a sufficient number of pixels to yield the desired statistical precision (e.g., 400 pixels to provide 5 percent precision), and determine its mean value.
2. Examine the signal from each pixel in the entire image and assign a gray level to each pixel according to the magnitude by which the signal differs from the mean value at the center ROI. Pixels with signal magnitudes differing by less than 10 percent from the mean value shall be assigned a neutral gray level. Pixels whose signals are more than 10 percent greater than the mean value, but less than 20 percent greater, shall be assigned the next lighter gray level. Pixels whose signals are more than 10 percent smaller than the mean value but less than 20 percent smaller, shall be assigned the next darker gray level. Pixels with signals more than 20 percent greater than the mean value shall be white, and pixels with signals more than 20 percent smaller than the mean value shall be black.
3. The indicated procedure, with 10 percent steps in magnitude of deviation, yields a 5-gray-level representation.
4. Display the gray-scale-coded image on the monitor to readily visualize the amount, the magnitude, and the location of nonuniformities in the image. Since nonuniformity location in the image is correlated with the cause of the nonuniformity, the coded image is performance-diagnostic tool for system adjustment. Supply a copy of this coded image with the measurement report.

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NEMA STANDARDIZATION

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 purchasers 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.

(Standardization Policies and Procedures, p. 1)

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, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(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.8)

Categories of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
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, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(Standardization Policies and Procedures, pp. 7 & 16)

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. 7 & 16)

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. 7 & 16)

Identification of Status

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.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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