NEMA MS 3

Determination of Image Uniformity in Diagnostic Magnetic Resonance Images

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Determination of Image Uniformity
in Diagnostic Magnetic Resonance Images

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Preamble

This is one of a series of test standards developed by the medical diagnostic imaging industry for the measurement of performance parameters governing image quality of magnetic resonance (MR) imaging (MRI) 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 Section 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 equivalent to the NEMA standard. The validity or equivalence of the modified procedure will be determined by the reader.

Uncertainty of the Measurements

The measurement uncertainty of the image quality parameter determined using this standards publication 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 is classified as a NEMA standard unless otherwise noted. It is intended for use by MRI system manufacturers, manufacturers of accessory equipment (including radio-frequency coils) and MRI end users.

The purpose of this standards publication is to provide a standard procedure for measuring and reporting image-intensity uniformity in an MRI system.

Image uniformity refers to the ability of an MR imaging system to produce an identical signal response throughout the scanned volume when the object being imaged is homogenous. Image-intensity nonuniformity in a two-dimensional MR image of a uniform test object can be caused by a number of factors, including RF coil geometry and penetration, nonuniformity of the transmitted RF field (B_1 nonuniformity), inhomogeneity of the static magnetic field (B_0 nonuniformity), inadequacies in gradient pulse calibration or eddy current corrections, and spatial positioning of the phantom.

Image uniformity is quantified here in terms of the deviation of the image pixel intensities from the midrange value. The analysis of uniformity shall be performed over the region of interest that is typically occupied by clinical samples and not over the full available volume of the RF coil.

This standards publication has been developed by the Magnetic Resonance Section of the National Electrical Manufacturers Association. User needs have been considered throughout the development of this publication. Proposed or recommended revisions should be submitted to:

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Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the section was composed of the following members:

Aurora Imaging Technologies—North Andover, MA
Fonar Corporation—Melville, NY
GE Medical Systems, Inc.—Milwaukee, WI
Hitachi Medical Systems America, Inc.—Twinsburg, OH
IGC Medical Systems—Milwaukee, WI
Philips Medical Systems (Cleveland), Inc.—Cleveland, OH
Siemens Medical Solutions, Inc.—Malvern, PA
Toshiba America Medical Systems—Tustin, CA
USA Instruments, Inc.—Aurora, OH

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Rationale

This Standard measures image nonuniformity (see 1.3) to characterize the low spatial frequency nonuniformities typical of MR images. It is important to quantify image nonuniformity because it alters image contrast.

Various factors influence MR image nonuniformity such as B1 nonuniformity (both in transmit and receive), quality of B0 shim, geometric distortion etc. Various techniques exist to correct for some forms of image nonunifomity such as RF receive coil correction algorithms. Other algorithms alter image uniformity in the process of correcting for some other factor, such as geometric distortion correction. Consequently, it is important that all correction algorithms used to produce the final image, which influence image uniformity and cannot be disabled, be identified when reporting uniformity measurement results.

This standard characterizes image nonuniformity qualitatively with a gray-scale uniformity map and quantitatively with simple figures of merit that analyze the range of pixel intensities relative to some measure of the average image intensity.

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Scope

This document defines a method for measuring image-uniformity performance of diagnostic magnetic resonance imaging systems using volume coils and performing proton imaging. This document does not address the use of surface coils, chemical shift imaging, or spectroscopy.

Image uniformity can be characterized in a number of different ways. The choice of a measurement and reporting method was guided by a desire for simplicity, accuracy, and ease of implementation on all MR systems. The peak deviation method represents a single image test that can quickly determine and report uniformity with a single number. It works best with very high SNR images. The gray-scale uniformity map image represents a single image test that can visually describe image uniformity.

Measurements are made over a volume that is representative of the region used for typical clinical studies. Due to the difficulty in handling large phantoms, it is permitted to use a test phantom that only covers 85% of the specification area.

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Section 1
DEFINITIONS

1.1 DATA ACQUISITION PARAMETERS

The following data acquisition parameters, and any other parameters necessary to repeat the measurement, must accompany the statement of the image uniformity number:

Parameter	Dimension
Phantom filler T1	milliseconds
Phantom filler T2	milliseconds
Phantom filler specific conductance (or phantom fillercomposition)	siemens per meter
Pixel bandwidth	Hz per pixel
Receiver channel 3dB bandwidth	kHz
Sequence repetition time (TR)	milliseconds
Echo delay time (TE)	milliseconds
Number of signals averaged (NSA)	….
Data acquisition matrix size	….
Field of view	millimeters
Pulse sequence name	….

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.

An absence of image nonuniformity (N) is defined as N=0% and perfect image uniformity (U) is defined as U=100%. The relationship is: U = 1 - N.

1.4 PEAK DEVIATION UNIFORMITY

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

1.5 GRAY-SCALE UNIFORMITY MAP

The percentage deviation from a midrange pixel value expressed in a gray-scale image format.

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.

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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 cm diameter spherical volume (dsv) centered in the RF head coil, and similarly for body scans, it must enclose, as a minimum, a 20 cm 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:

a. Head specification volume: in the image plane the phantom shall enclose, as a minimum, a 10 cm diameter circle or 85% of the specification area, whichever is larger.
b. Body specification volume: in the image plane, the phantom shall enclose, as a minimum, a 20 cm diameter circle or 85% 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:

a. T1 < 1200 milliseconds (at operating field strength)
b. T2 > 50 milliseconds (at operating field strength)
c. Spin density = density of H20 $\pm$ 20% (Take care to select some material that does not cause undue dielectric resonance effect.)

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:

a. The phantom shall be centered in the RF receive coil;
b. Room and phantom temperature shall be 22±4^{o}C;
c. TR $\geq$ 5XT1 of the filler material in the signal producing volume;
d. TE within the clinically selectable range;
e. The selected field of view shall not exceed 110 percent of the largest linear dimension of the RF coil in the image plane;
f. Spin echo pulse sequence (first echo);
g. Slice thickness $\leq$ 10 mm; and
h. Data acquisition matrix size $\geq$ 128x128;
i. All user selectable image filters to be disabled.

2.3 MEASUREMENT PROCEDURE

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

a. Center the signal producing volume of the phantom in the RF receive coil;
b. Perform the standard clinical pre-scan calibration procedure as recommended by the system manufacturer; and
c. Execute the scan(s). Increase the number of signals averaged and/or decrease data matrix size (see 2.2h) to increase image SNR, if needed.
d. Analyze the image uniformity data as described in 2.3.2 or 2.3.3. Pre-processing of the image data is permitted, as described in 2.3.1.

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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_l,m_2). The filtered image is given by:

$$S(n_1,n_2) = \frac{1}{W}\sum_{m1=-1}^{1}\sum_{m2=-1}^{1} h(m_1,m_2)I(n_1 - m_1, n_2 - m_2)$$

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:

$$W = \sum_{m1=-1}^{1}\sum_{m2=-1}^{1} h(m_1,m_2)$$

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 Peak Deviation Uniformity

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

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

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

$$\overline{S} = \frac{S_{max} + S_{min}}{2} \quad (2)$$

The ratio of Δ to $\overline{S}$ is multiplied by 100, and expressed as a percentage uniformity.

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The Peak Deviation Uniformity measure (N) is defined as:

$$N = 100\frac{\Delta}{\overline{S}} = 100\frac{S_{\max} - S_{\min}}{S_{\max} + S_{\min}} \quad (3)$$

The peak deviation uniformity measure is sensitive to image SNR. As SNR decreases, S_{max} and S_{min} diverge, lowering computed peak deviation uniformity.

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. If the ROI is in a region with anomalous signal characteristics (e.g. center of high signal intensity caused by dielectric resonance) use the mean from the MROI.

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 produces a five gray-level representation of the image nonuniformity with the following ranges relative to the mean value:

a. lowest signal value to -20%
b. -20% through -10%
c. -10% through +10%
d. +10% through +20%
e. +20% through to highest signal value

These five unequally sized bands visualize the location and structure of nonuniformities without showing the complex structure immediately surrounding the coil elements.

4. Display the gray-scale coded image on the monitor to readily visualize the amount, the magnitude, and the location of non-uniformities 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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Section 3
SOURCES OF ERROR AND REPORTING OF RESULTS

3.1 SOURCES OF ERROR

The following sources of error shall be discussed and reported:

- Uncertainty due to SNR limitations
- Image artifacts
- Other errors

The peak deviation uniformity measure requires high image SNR for accurate measurements. Verify that image SNR is sufficient.

3.2 REPORTING OF RESULTS

3.2.1 SCAN PARAMETERS:

The following scan parameters, and any other parameters necessary to repeat the measurement, must accompany the statement of the image uniformity (N or U) or the gray scale uniformity map:

Parameter	Dimension
Phantom filler T1	milliseconds
Phantom filler T2	milliseconds
Phantom filler specific conductance (or phantom filler composition)	siemens per meter
Pixel bandwidth	Hz per pixel
Receiver channel 3dB bandwidth	KHz
Sequence repetition time (TR)	milliseconds
Echo delay time (TE)	milliseconds
Number of signals averaged (NSA)	….
Data acquisition matrix size	….
Field of view	millimeters
Pulse sequence name	….
Receive/Transmit coil(s) used	…
Phantom size	millimeters
MROI size	millimeters
Scan plane	T/S/C
Signal to Noise Ratio	…
Type of pulse sequence used and other relevant acquisition parameters	…
Type of signal filters used (time and/or image domain)	…
Statement of geometric distortion correction algorithm	…
Statement of RF receive coil correction algorithm	…

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Annex A
CHANGES TO STANDARD

A.1 CHANGES TO MS 3-1989 RESULTING IN MS 3-2003

A.1.1 Summary

It is emphasized that the peak deviation (integral) uniformity measure is sensitive to the signal to noise level (SNR) of the image. Reduced data acquisition matrix size and increased number of signal averages can be used to improve SNR.

The method for measuring “integral uniformity” is derived from the Gamma Camera standard. It has been renamed to peak deviation uniformity for MRI purposes. Additionally, the meaning of uniformity versus nonuniformity has been clarified.

Changes were made to the Gray-Scale Uniformity Map technique to reflect improvements in transmit/receive coil designs. The small ROI mean definition can produce a skewed mean value which consequently will alter the gray scale.

A.1.2 Changes to introduction

- "Notice and Disclaimer" section added.
- Rationale section expanded.
- Scope section expanded. The operating scope of the various uniformity measurement methods are described. The reason why undersized specification regions are permitted is also explained.

A.1.3 Section 1

- Voxel dimension definitions deleted. Definition too simplistic and not relevant to this standard.
- Definition of image nonuniformity vs uniformity added.
- Renaming of Integral Uniformity measure to Peak Deviation Uniformity measure. The original concept of Integral Uniformity was borrowed from the Gamma Camera standard.

A.1.4 Section 2

- Spin density requirement wording changed to reflect emergence of higher field units beyond 1.5T.
- (+/-) removed from Equation 3.
- Limitations of peak deviation method described.
- Limitations to matrix size to avoid impact of ringing artifact on uniformity measurement.
- Gray Scale Uniformity Map method changed to permit the mean to be computed from the ROI or MROI. This alternate way of computing the mean is necessary to avoid particularly high or low signal intensity regions which might be at the center of the image (e.g. a bright signal region resulting from dielectric resonance effects).

A.1.5 Section 3

- Section 3 added to be consistent with the other NEMA standards.
- Require the reporting of rf coil or geometric distortion correction algorithms. These algorithms may alter image uniformity.

A.1.6 Annex A

Annex A added to highlight changes between versions of this standard

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