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Determination of Two-Dimensional Geometric Distortion 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.

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 special purpose gradient coils), and MRI end users.

The purpose of this procedure is to provide a standard means for measuring and reporting two-dimensional geometric distortion in an MRI system. Two-dimensional geometric distortion is defined here as the maximum percent difference between measured distances in an image and the actual corresponding phantom dimensions. Radial measurements, i.e., between points spanning the geometric center of the test object, are used to characterize the geometric distortion. Measurements will be evenly spaced with an angular separation less than or equal to 45º in order to sample sufficiently the angular variation of geometric distortion.

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:

Computer Imaging Reference Systems—Norfolk, VA
Confirma, Inc.—Bellevue, WA
GE Healthcare, Inc.—Milwaukee, WI
Hitachi Medical Systems America, Inc.—Twinsburg, OH
Invivo Corporation, Gainesville, FL
Medipattern Corporation—Toronto, ON, Canada
Philips Healthcare—Andover, MA
Siemens Medical Solutions, Inc.—Malvern, PA
Toshiba America Medical Systems—Tustin, CA

Rationale

One of the essential attributes of an MRI scanner is its ability to produce a two-dimensional map, or image, of the nuclear magnetic resonance (NMR) signal as a function of position within the object under study. It is natural, therefore, to seek to determine the extent to which the spatial relationships in the image correspond to the actual spatial relationships in the object.

Geometric distortion in a two-dimensional MRI image can be caused by a number of factors, including, but not limited to, inhomogeneity of the main magnetic field (B_0), gradient field nonlinearity, gradient amplitude miscalibration, eddy current effects, and magnetic susceptibility effects. A number of specialized techniques have been developed to identify particular sources of geometric distortion, to quantify and in some cases to correct for the distortions introduced. For example, magnetic field mapping and shimming techniques are essential tools employed by the MR system manufacturer to reduce B_0 inhomogeneities to a minimum. Nevertheless, geometric distortion correction algorithms are sometimes employed in the reconstruction of an image in order to further reduce distortions. Such algorithms are permitted under this standard, so long as they are an integral step in the reconstruction of an image.

Two-dimensional geometric distortion in an MR image can be characterized in a number of different ways. The choice of a measurement and reporting method was guided by a desire for computational simplicity and ease of implementation on all MR systems. It was also intended that the results could be obtained in a relatively short time. Consequently, a simple figure of merit was chosen to characterize the two-dimensional geometric distortion likely to be encountered when using a typical clinical pulse sequence. Because readout gradient strength has a direct bearing on the degree of in-plane distortion due to static field inhomogeneity, the imaging bandwidth chosen for this test must accompany the report of results.

Scope

This standards publication describes a method for determining the maximum percent difference between measured distances in an image and actual corresponding phantom dimensions. The procedure described evaluates geometric distortion in three orthogonal planes passing through the center of the specification volume.

This procedure does not address the question of the absolute positional accuracy of the image of the test object in the frame of reference of the magnet. Only the relative separation of selected points on the test object is considered. This procedure does not address the measurement of slice flatness or the accuracy of slice positioning.

History

MS 2-2003 differs from its predecessor MS 2-1989 in the following ways:

1. A Rationale has been added.
2. The Scope of the standard has been more precisely delineated.
3. The scan conditions explicitly stipulate that the spatial resolution be the same in the frequency- and phase-encoding directions.
4. Geometric distortion correction algorithms are permitted so long as they are an integral step in the reconstruction of an image. These were not considered in the predecessor standard.
5. Numerous editorial changes have been made to improve readability.

MS 2-2008 differs from its predecessor MS 2-2003 in the following way:

The definition for “Specification Volume” has been revised.

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Section 1
DEFINITIONS

1.1 SPECIFICATION VOLUME

The specification volume is the imaging volume within which a manufacturer guarantees image performance specifications. Images or portions of images outside this volume may not necessarily meet performance specifications, but may still be useful for diagnostic purposes. For head scans, the specification volume must enclose, as a minimum, a 10 centimeter diameter spherical volume (dsv) centered in the RF head coil. For body scans, the specification volume must enclose, as a minimum, a 20-cm dsv centered in the RF body coil.

1.2 SPECIFICATION AREA

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

Section 2
METHODS OF MEASUREMENT

2.1 PHANTOM DESIGN

The phantom shall be designed so that geometric distortion can be measured over the perimeter of the entire specification area.

The phantom shall consist of a series of rings, holes, pins, or other defined edges that follow the perimeter of the specification area.

The phantom shall be at least twice as thick as the slice thickness used in the measurement to minimize the influence of slice curvature.

RF coil loading need not be considered in the design of the phantom since RF coil loading will not affect the distortion measurement.

2.2 SCAN CONDITIONS

Image data shall be acquired using a typical clinical pulse sequence and reconstruction process. In this context, a typical clinical pulse sequence is one that might be relied upon for an accurate determination of the dimensions of an anatomical structure or feature. In addition, the following scan conditions shall obtain:

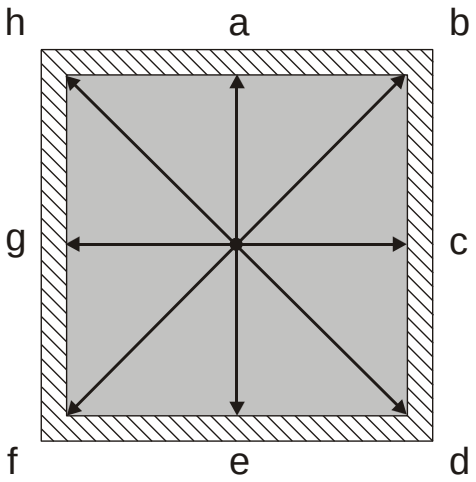
1. Phantom centered in the RF receive coil;
1. Room and phantom temperature in the range 22 ± 4□□C;
2. Spin echo pulse sequence (first echo);
3. TE (echo time) and TR (repetition time) within the clinically selectable range;
4. Single-slice acquisition centered at isocenter;
5. Field of view of the scan selected so that both pixel dimensions shall be □ 1 percent of the maximum dimension of the specification area in order to minimize errors due to large pixel size;
6. Slice thickness □ 10 mm;
7. Square pixel encoding (identical spatial resolution in frequency and phase).

2.3 MEASUREMENT PROCEDURE

The phantom shall be positioned and the data acquired as specified in Section 2.2.

Separate scans shall be performed in the three orthogonal planes (axial, sagittal, and coronal) passing through the center of the specification volume.

The distance between diametrically opposed pairs of points shall be measured. The phantom shall have at least four pairs of evenly distributed reference points that lie on the perimeter of the specification area. The lines connecting these points pass through the phantom center. The angles between pairs of adjacent connecting lines shall be less than or equal to 45°. Refer to Examples 1, 2, and 3.



The gray area is both the specification area and the liquid in the phantom.

The striped area is the plastic wall of the phantom.

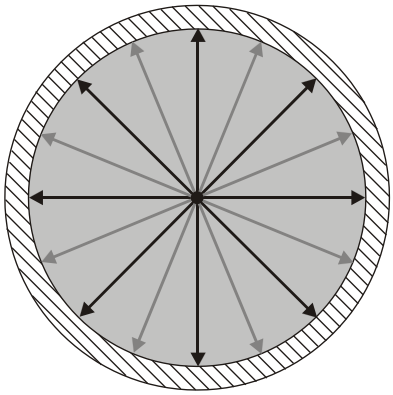
Evaluation

Line segment	Measured on image (mm) L_m	Actual phantom dimension (mm) L_a	Absolute difference (mm) $\lvert L_m - L_a \rvert$	Percent difference $100 \times \lvert L_m - L_a \rvert / L_a$
Ae	197	199	2	1.0
Bf	285	282	3	1.1*
Cg	201	200	1	0.5
Dh	281	282	1	0.4

*maximum to be reported

Example 1

The specification volume is cubic, and the specification area is square. The signal-producing region of the phantom matches the specification area exactly. The four distances shown are measured on the image and compared to the actual phantom dimensions.

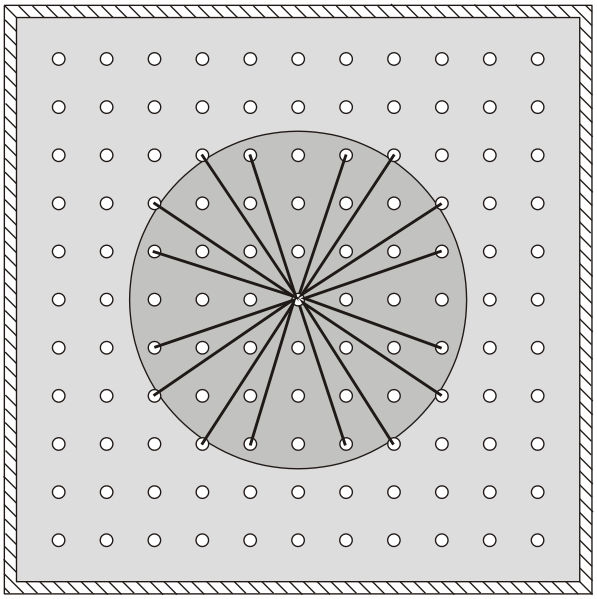


The gray area is both the specification area and the liquid in the phantom.

The striped area is the plastic wall of the phantom.

Example 2

The specification volume is spherical, and the specification area is a disk. The signal-producing region of the phantom matches the specification area exactly. The four distances indicated with black arrows are measured on the image and compared to the actual phantom diameter. Additional measurements (shown by gray arrows) are suggested. A central pin in the phantom is useful, but not essential, for ensuring that each of the measurements represents a diameter.



The darker gray area is the specification area.

The striped area is the plastic wall of the phantom.

The lighter gray area is within the phantom, but not in the specification area.

The small circles mark the positions of pins in the phantom.

Example 3

The specification volume is spherical, and the specification area is a disk. The signal-producing region of the phantom extends beyond the specification area. After selecting pins that approximate the periphery of the specification area, diameters are constructed and measured on the image; these are compared to the actual corresponding distances in the phantom.

Section 3
REPORTING OF RESULTS

3.1 REPORTING OF TWO-DIMENSIONAL GEOMETRIC DISTORTION

Geometric distortion for each of the orthogonal scans shall be reported as the maximum absolute difference (in percent) between any of the measured distances and the actual corresponding phantom dimensions, i.e.,

$$\text{geometric distortion} = \text{MAX}\{100 \times |L_m - L_a|/L_a\}$$

where:

L_m = distance measured on image, and
L_a = actual phantom dimension

(see table in Example 1).

The statement or quotation of geometric distortion shall be accompanied by the following parameters:

1. Specification volume (description and dimension)
2. Phantom description and dimensions
3. A description of scan conditions and parameters sufficient to ensure repeatability. In addition to the scan parameters specified in Section 2.2, this shall include:
4. Pixel bandwidth (hertz per pixel)
5. Read-out gradient direction
6. Voxel dimensions
7. Scan plane orientation
8. Geometric distortion correction algorithm used, if any.

The statement or quotation of geometric distortion shall be accompanied by an estimate of the measurement error, supported by a listing and discussion of sources and magnitudes of error.

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