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Characterization of the Specific Absorption Rate (SAR) for Magnetic Resonance Imaging Systems

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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 related to the safety 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 the 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.

Foreword

Unless otherwise noted, this publication has been approved as a NEMA standard. It describes the test conditions and parameters that ensure accurate measurement of the Specific Absorption Rate (SAR). This Standard does not attempt to establish relationships between SAR and body temperature.

This standards publication was developed by the Magnetic Resonance Section of the National Electrical Manufacturers Association.

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.

GE Healthcare, Inc. – Milwaukee, WI.

Hitachi Medical Systems America, Inc. – Twinsburg, OH.
Invivo – Gainesville, FL.

Medipattern Corporation – Toronto, Ontario.

Medtronic Navigation – Yokneam, Israel.

Philips Healthcare – Bothell, WA.

Siemens Medical Solutions, Inc. – Malvern, PA.

Toshiba America Medical Systems – Tustin, CA.
AllTech Medical Systems America – Solon, OH.

User needs have been considered throughout the development of this publication. Proposed or recommended revisions should be submitted to:

Executive Director, Medical Imaging & Technology Alliance
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Introduction

In magnetic resonance (MR) imaging, radiofrequency (RF) magnetic fields are used to interrogate a region of interest. These RF fields induce currents in the body, which may lead to heating. It is not considered prudent to raise the core temperature in a patient above 39.2°C (roughly a 2.2 degree rise from thermoneutral) (1,2). If patient exposure to radiofrequency magnetic fields during MR scanning is insufficient to produce a core temperature rise in excess of 1°C and localized heating greater than 38°C in the head, 39°C in the trunk, and 40°C in the extremities, RF heating is considered to be within safe levels (3,4,5,6).

Parameters such as bore temperature, ambient temperature, relative humidity, air flow rate, perspiration, and blood flow influence temperature rise in the patient. A key variable in determining patient heating potential in an MR scanner is the power absorbed per unit mass, which is the Specific Absorption Rate (SAR). An insulated slab of tissue initially at thermal equilibrium with its environment increases in temperature at a rate of approximately 1°C per hour when exposed to a SAR of 1 W/kg.

The MR scanning process applies a train of RF pulses, which have specific, calibrated tip angles. Each pulse results in some power absorption in the patient. The highest absorbed energy per pulse takes place in those patients whose cross-sectional area is greatest. The highest absorbed power (and SAR) takes place in such patients when they are exposed to the highest permitted RF duty cycle. The greater the number of images (slices/echoes) per unit time the greater the SAR. Note that scan time implies the length of time the scanner gradient or RF hardware is employed to produce an image. For example, the period over which the SAR from an echo planar scan is averaged is the entire time required to pulse the RF and gradients, not merely the pulse duration of the initial RF pulse.

There is a need to measure SAR for developing and verifying various predictive safety algorithms. To this purpose, measurements of SAR in phantoms with electrical conductivities similar to patients are important. This standard was developed to fill these needs.

Determination of SAR may be done either calorimetrically or by measurements of energy per pulse. In the calorimetric method the absorbed RF power is measured directly, while the pulse energy method measures the net power delivered to the transmit coil less the reflected losses to determine the remaining absorbed power. The pulse energy method may be used to determine SAR either in a phantom or a patient. Both methods are described in this standard; either method may be chosen. The pulse energy method permits the use of low duty cycle scans for the test. The results from either method may then be extrapolated to other scan parameters and even to other waveforms.

Local SAR measurements are important for assessing localized heating. The local average SAR is the total power divided by the exposed mass. The (spatial) peak SAR is the SAR in the highest SAR occurring in any 10 grams of tissue. While peak and local SAR levels are important in localized heating, they are difficult to measure directly in living patients. For this reason, determinations of peak and local SAR levels are beyond the scope of this document.

An addition has been made to this standard that takes into account variations in coil power loss that have been observed since the last publication of the standard. Note that the variation is higher for the relatively newly introduced 70 cm and 3T systems compared to the old standard 1.5T systems. This variation affects directly the SAR estimate because the transmit coil power loss is not constant. Additionally, the calorimetric SAR verification is affected because of the necessary step of finding the patient equivalent mass of phantom 2.

Scope

This NEMA Standards Publication describes two measurement procedures for whole-body SAR measurements, the calorimetric method and the pulse-energy method. Extrapolation of these data to patient temperature rise is beyond the scope of this document. This document does not apply to gradient (low-frequency time-varying magnetic fields) safety where nerve and cardiac excitation are the primary safety issues. Neither is it intended to apply to spatial peak or local average SAR nor does it address other factors involved with patient heating. The tests specified are only for volume RF transmit coils that produce relatively homogeneous RF fields.

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 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 procedures will be determined by each reader.

Uncertainty of the Measurements

The measurement uncertainty of the 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.