EVALUATION OF SPECIFIC ABSORPTION RATE AMONG PATIENTS USING 3 TESLA AND 1.5 TESLA MAGNETIC RESONANCE IMAGING MACHINES

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Abstract

Background: Specific Absorption Rate (SAR) is radiofrequency power delivered to tissue during a Magnetic Resonance Imaging (MRI) examination, expressed as watts per kg (W/kg). Radiofrequency power deposition results in increased heating of patient tissues; thus, the use of MRI has to be controlled to ensure patient safety.

Objective: The study aimed to evaluate SAR among patients using the 3 Tesla MRI (MRI 3T) and 1.5 Tesla MRI (MRI 1.5T) machines.

Methods: Data were obtained from patients who were examined using MRI 3T (1,159 patients, 8,225 series) and MRI 1.5T (1,423 patients, 8,605 series) machines. Age, body weight, SAR, repetition time (TR), type of radiofrequency (RF) pulse and anatomical region exposed were studied.

Results: Average SAR for all patients using the MRI 3T was lower than that of the MR 1.5T in every part (p <0.001) = 0.92 ± 0.57 W/Kg, 2.45 ± 1.01 W/Kg, accordingly. The SAR that the patients received using the spin echo technique revealed that T2 weighted image had lower SAR than T1 weighted image from both MRI 3T and MRI 1.5T (p < 0.001), 0.87 and 0.98 W/kg for MRI 3T, 2.20 and 2.83 W/kg for MRI 1.5T, respectively. For underweight patients, the lowest SAR was 0.89 W/Kg (MRI 3T) and 2.40 W/Kg (MRI 1.5T), respectively. Whereas, among overweight patients, the SAR was the highest at 0.97 W/Kg (MRI 3T) and 2.52 W/Kg (MRI 1.5T). For SAR categorized by the flip angle of the RF pulse, and patients evaluated by the MRI 3T, the study revealed that the group with the flip angle of the RF pulse <75 degrees had lower SAR than the flip angle of the RF pulse >75 degrees, 0.77 W/Kg and 0.94 W/Kg, accordingly (p < 0.001) similar to the MRI 1.5T.

Conclusion: The average SAR of patients evaluated using the MRI 3T was lower than those of patients evaluated using the MRI 1.5T in every body part examined. SAR was lower when the TR was increased and flip angle was decreased.

Keywords: Specific Absorption Rate (SAR), 3 Tesla MRI machine, 1.5 Tesla MRI machine

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Introduction

The magnetic resonance imaging (MRI) machine is an important diagnostic tool generating imaging using an electromagnetic field and the spinning of the nucleus of the hydrogen atom which is the fundamental composition in the human body such as in the water molecule (H_2O). The magnet embedded within the MRI scanner can act on these positively charged hydrogen ions (H^+ ions) and cause them to 'spin' in an identical manner. Varying the strength and direction of this magnetic field can change the direction of the 'spin' of the protons, enabling us to build layers of detail. When a patient enters the MRI machine, it would transmit a radiofrequency (RF) wave at a specific radio frequency transforming into heat within the patients' tissue. When the magnet is switched off, the protons will gradually return to their original state in a process known as precession. Fundamentally, the different tissue types within the body return at different rates allowing us to visualize and differentiate between the different tissues of the body to distinctly detect abnormalities for diagnosis.

As the electromagnetic radiation that is used is the non-ionizing radiation, the energy of the radio waves is not sufficiently high to cause the disintegration of the charges in the atoms or molecules [1]. However, related studies have indicated that electromagnetic waves alter the body's biology and affects vision, hearing, the endocrine system, the nervous system, the cardiovascular system, the immune system and the reproductive system. These biological alterations occur due to the induction of heat from the electromagnetic waves that the body receives, [2-11] which are used to create MR images, most significantly from the induction of the magnetic fields [12-21]. The rise in the body temperature of the patients by the electromagnetic waves, depends on several factors related to the regulation of body temperature and control of the environment [3-8]. The temperature changes and other body changes from the reception of electromagnetic waves depend upon the amount of energy that the body absorbs, called the specific absorption rate (SAR) [2-4]. This is the value that depicts the amount of heat per mass of the tissue or the body part that is receiving the energy from electromagnetic waves. This value is measured in watts/kg (W/kg)[2-4] and constitutes a factor affecting the calculation of SAR while the MRI is obtained including, but not limited to, the flip angle of the RF pulse, the repetition time (TR), the type of the RF coil, the anatomical region exposed and the patient's body weight[19-22].

The Food and Drug Administration (FDA) [23] has recommended that the SAR should not exceed the value indicated below to decrease the risks involved from using radio waves on the patient. The average SAR of the body should not exceed 4 W/kg in 15 minutes, the average SAR of the head should not exceed 3 W/kg in 10 minutes, the average SAR of the head and body should not exceed 8 W/kg in 5 minutes and the average SAR of the arms should not exceed 12 W/kg in 5 minutes. Therefore, MRI machines have been programmed, to be alerted to and immediately terminate when the patient is being examined using the MRI machine and the SAR exceeds the set limits [23]. The study aimed to compare the SAR recorded among patients undergoing MRI using MRI 3T and MRI 1.5T machines. The result of this study would help to adjust the parameters used for the MRI machine to evaluate patients to further increase safety and efficacy of the MRI.

Methods

This study employed a retrospective descriptive study design approved by the Ethics Committee, Institutional Review Board, Royal Thai Army Medical Department (S013h/61). The inclusion criteria comprised data sets including the parameters SAR, age, weight, SAR, repetition time, type of RF pulse and anatomical region exposed recorded from the MRI studies and information only obtained from patients who were 16 years of age or above. The exclusion criteria included any incomplete data sets that did not have all required information on the parameters. The appropriate sample size calculated for each MRI machine was at least 8,182 series of images. Simple random sampling was employed using computer generated simple random samples from data sets from both MRI machines obtained from January to December 2018.

Collecting data from patients evaluated using the MRI 3T model Philips Achieva 3.0T TX (1,159 patients, 8,225 series) and 1.5 T model Philips Achieva 1.5T XR (1,423 patients, 8,605 series) using the DoseMonitor Program by PACSHealth, LLC included age, body weight and specific absorption rate (SAR), repetition time (TR), type of RF pulse and anatomical region exposed. Data acquisition was achieved by sending Digital Imaging and Communications in Medicine (DICOM) of the MRI to the Dose Monitor Program. The program obtained the data from the DICOM header and exported the data in the form of an Excel file.

The SAR values, as estimated by the MR system console, were noted from the DICOM, allowing the data to be categorized in two groups of body weight based on the Thai body shape and body database (SizeThailand)[24]. The range of the body weight used was the normal weight range of the average weight of Thai men and women ± 5 kg. The age group was divided and subdivided in underweight patients (<58 kg), normal weight (58-68 kg) and overweight (>68 kg), SAR and TR. The patients with T1 weight image in spin echo pulse sequence (SE) would have TR <800 msec and those with T2 weight image SE would have TR >2,500 msec[25]. Data also included the flip angle of the RF pulse divided in a group with flip angle <75 degrees and a group with flip angle >75 degrees.

The statistics used included mean and standard deviation. For qualitative analysis, the data included the type of coil and the anatomical region exposed; which were divided into the head and neck, spine, abdomen and extremities; as percentile. To compare differences between the SAR among patients evaluated using the MRI 3T versus those that were evaluated using the MRI 1.5T; the unpaired t-test was used to compare the means of two unmatched groups, and one-way analysis of variance (ANOVA) was used to determine any statistically significant differences between three independent groups, where the level of significance was 0.05.

Results

The demographic information of the patients who had undergone MRI using the MRI 3T machine revealed mean age of 44.82 ± 19.66 years and mean body weight of 65.45 ± 14.59 kg. In total, 8,225 series of images were divided into 2,551 series of head and neck images, 2,142 series of spine images and 3,532 series of extremities images as shown in **Table 1.**

Table1. Demographics of participants imaged with 3 Tesla MRI and 1.5 Tesla MRI of each organ
.

Variables	Magnetic Field Strength		
	3 T N=8,225 Series	1.5 T N=8,605 series	*p*-value
Gender (*%*)	Male=4,761 (57.88) Female=3,464 (42.12)	Male =4,557 (52.96) Female=4,048 (47.04)	<0.001
Age Years, Mean (SD)	44.82 (19.66)	54.63 (17.39)	<0.001
Weight kg. Mean (SD)	65.45 (14.59)	63.27 (12.07)	<0.001
Anatomical region exposed:			
Head & Neck	2,551	2,443	<0.001
Spine	2,142	2,225	<0.001
Extremities	3,532	3,937	<0.001

Note: n = number of series of images

The general demographic information of the patients that had undergone MRI in the 1.5T machine revealed mean age of 54.63 ± 17.39 years and mean body weight of 63.27 ± 12.07 kg. In total 8,605 series of images were divided into 2,443 series of head and neck images, 2,225 series of spine images and 3,937 series of extremities images.

The average SAR of all the patients that had been evaluated using the 3T MRI machine was significantly lower that the SAR of those that had been evaluated using the 1.5T MRI machine (*p* <0.001) SAR = 0.92 ± 0.57 W/Kg and 2.45 ± 1.01 W/Kg, accordingly. When categorized and analyzed according to the anatomical regions exposed, patients that had been evaluated using the 3T and the 1.5T machines showed the least SAR in the head and neck studies and the SAR from the 3T machine was significantly lower than the 1.5T machine, p-value <0.001) SAR = 0.21±0.20 W/kg and 1.87 ± 1.05 W/kg, accordingly. The anatomic region exposed having the highest SAR among the patients that were evaluated by the 3T machine was the spine = 1.39± 0.37 W/kg whereas the anatomic region exposed that had the highest SAR among the patients that were evaluated by the 1.5T machine was the extremities = 2.80± 0.84 W/kg as shown in **Table 2.**

SAR for patients who were imaged using the spin echo technique found that T2 weight image (long TR >2500 msec) had significantly higher SAR than T1 weight image (short TR <800 msec) in both MRI 3T and the MRI 1.5T machines (*p* <0.001), 0.98 and 0.87 and 0.98 W/kg for 3T, 2.20 and 2.83 W/kg for 1.5T. When considering the SAR value by weight groups, the underweight group (<58 kg) had the lowest SAR = 0.89W/kg (MRI 3T), 2.40 W/kg (MRI 1.5T) and the overweight group (>68 kg) had the highest SAR = 0.97 W/kg (MRI 3T), 2.52 W/kg (MRI 1.5T). When comparing the SAR the patient received from the MRI 3T machine, the SAR in the underweight (0.89 W/kg), normal weight (0.90 W/Kg) and overweight (0.97 W/Kg) groups significantly differed (*p* < 0.001). When comparing the SAR that patients received from the 1.5T MRI machine, the SAR of the underweight (2.40 W/Kg), normal weight (2.44 W/Kg) and overweight (2.52 W/Kg) groups significantly differed (*p* < 0.001) as shown in **Table 3**.

When analyzing the SAR categorized by the flip angle of the RF pulse among patients examined by the 3T MRI machine, the group with the flip angle of the RF pulse <75 degrees received significantly less SAR than the group with the flip angle of the RF pulse >75 degrees, which were 0.77 W/kg and 0.94 W/kg, accordingly (*p*=0.001). Similarly, among patients examined using the 1.5T MRI machine, the group with the flip angle of the RF pulse <75 degrees received significantly less SAR than the group with the flip angle of the RF pulse >75 degrees, i.e., 2.18 W/kg and 2.48 W/kg, accordingly (*p* = 0.001).

Table 2. Specific absorption rates among patients evaluated using the 3T and 1.5 MRI machines

Variables	Specific absorption rate (SAR)/ Type of coil		
	3 Tesla (mean±SD)	1.5 Tesla (mean±SD)	*p*-value
Anatomical region exposed:			
Head & Neck	0.21 ± 0.2*0*	1.87±1.05	<0.001
Spine	1.39 ± 0.37	2.41±0.90	<0.001
Extremities	1.09 ± 0.30	2.80±0.84	<0.001
Total	0.92 ± 0.57	2.45±1.01	<0.001

Table 3. Specific absorption rate (SAR) of each parameter used for patients who were evaluated using the 3T and 1.5 MRI machines

Variables	3 Tesla (n= 8,225)		1.5 Tesla (n=8,605)	
	SAR	*p*-value	SAR	*p*-value
Type of Image				
T1 weighted Image (TR < 700 msec)	0.93(n=3,319)		2.83(n=3,344)	
T2 weighted Image (TR >2,500 msec)	0.87(n=4,906)	<0.001	2.20(n=5,261)	<0.001
Weight Group				
Under weighted (<58 kg.)	0.89(n=2,620)		2.40(n=2,652)	
Normal weighted (58-68 kg.)	0.97(n=2,561)		2.44(n=3,331)	
Over weighted (>68 kg.)	0.90(n=3,044)	<0.001	2.52(n=2,622)	<0.001
Flip angle of RF Pulse				
< 75 degree	0.77(n=1,113)		2.18(n=715)	
> 75 degree	0.94(n=7,112)	<0.001	2.52(n=7,890)	<0.001

Note: n = number of series of images

Discussion

The average SAR value for all patients evaluated using the 3T MRI machine was lower than that of patients evaluated using the 1.5T MRI machine. This coincides with the study by Krishnamurthy[26] reporting that fetal brain images with higher resolution and better SNR with MRI 3.0T exhibited simultaneously reduced SAR compared with MRI 1.5T. In addition, the SAR received by the patients did not exceed the SAR limits set by FDA[23] which recommends that SAR for the whole body study should be lower than 4 W/kg within 15 minutes, for the head and neck should be lower than 3W/kg within 10 minutes and for the extremities should be lower than 12 W/kg within 5 minutes; to decrease the possible effects on the patient's tissues from the radio waves used in the MRI.

The SAR in studies where the spin echo technique was used showed that T2 weighted image (long TR > 2,500 music) had lower SAR than T1 weighted image (short TR < 800 msec) similar to the study by Allision et al.[27] and Chavhan et al.[28] showing that SAR decreased when TR increased. When considering the SAR according to weight group, for the underweight patients (<58 kg), the SAR was the lowest, 0.89 W/kg (3T), 2.40 W/kg (1.5T) and for the overweight patients (>68 kg) SAR was the highest = 0.97 W/kg (3T), 2.52 W/kg (1.5T). This coincides with the study by Gach et al. [29] revealing obese patients had a higher risk of absorbing heat from MRI than non-obese patients because obese patients required more field of view to scan.

When analyzing SAR according to the flip angle of the RF pulse, patients who were examined with the flip angle of the RF angle <75 degrees received less SAR than those examined with the flip angle of the RF pulse >75 degrees. This coincides with the study by Allison et al. [27] and Chavhan et al.[28] showing the SAR decreased when the flip angle decreased. The results of this study could help radiologists and MR technologists to experience greater confidence regarding the information that the SAR received by the patients not exceeding the SAR limits set by the FDA. In addition, the SAR decreased with decreased flip angle and increased TR.

Conclusion

The study revealed the average SAR of all patients, evaluated using the 3T MRI machine, was lower than those investigated using the 1.5T MRI machine for every anatomical region examined. For both of the MRI 3T and the MRI 1.5T groups, patients undergoing head and neck studies would have the lowest SAR. Overweight patients would receive higher SAR. SAR could be reduced when TR increased and the flip angle decreased.

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Potential conflicts of interest

The authors declare they have no conflict of interest.

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