

Temperature Changes in the Brain of Patients Undergoing MRI Examination

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Abstract

Magnetic Resonance Imaging scanners have become important tools in modern day health care. During the imaging process, total radiofrequency power is transferred from the RF coil to the brain tissues resulting in increase in temperature in the subject being imaged. Currently, reliable and validated means to predict RF heating are not unavailable. This research was conducted to determine temperature changes in the human brain during MRI examination. This study was carried out at two MRI Units in Ghana. One hundred and twenty-six patients were investigated. Data collected include pre- and post-scan tympanic temperatures and specific absorption rates values. The average pre- and post-scan tympanic temperatures measured for Centre A were 36.5 ± 0.1 °C and 37.0 ± 0.1 °C respectively with an average change in temperature of 0.5 ± 0.1 °C for 30.68 minutes scan and an average SAR value of 1.25 W/kg. Centre B measured average pre- and post-scan tympanic temperatures of 36.4 ± 0.1 °C and 36.8 ± 0.1 °C respectively with an average change in temperature of 0.4 ± 0.1 °C for 41.58 minutes scan and an average SAR value of 0.1 W/kg. The rise in tympanic temperature and SAR values were within guidance level of 1 °C recommended by the United States Food and Administration and the International Electrotechnical Commission.

Keywords: brain; MRI; pre- and post-tympanic scan temperatures; rise in temperature SAR

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1. Introduction

The core temperature in the human brain is a very important parameter which if not regulated could lead to brain damage. During magnetic resonance (MR) imaging, patients are subjected to electromagnetic fields [1] which deposit energy and as a result, temperature increase within patients is inevitable [2, 3]. According to the USFDA guidelines limit, the core temperature of the head must not be greater than 38 °C and it should not increase more than 1 °C [4] for patients during MRI procedures. This work therefore studies the rise in temperature for patients undergoing MRI brain examinations.

2. Materials and Method

Two different magnetic resonance (MR) systems of field strengths of 1.5 T and 0.3 T at Imaging Centres A and B respectively all located in Ghana were used for this study. Digital clinical thermometer was used to measure patient temperatures experimentally. The thermometer calibration was done at the Temperature Laboratory of the Ghana Standards Authority and ranges from 36 °C to 40 °C with a resolution of 0.1 °C. Under ambient conditions the thermometer reads (25±1) °C and relative humidity of (55±20) %. A combined weight and height scale was also used to measure patient weight and height.

Two groups of volunteer patients were investigated: those who were scanned using a magnetic field strength of 0.3T and 1.5T MRI machine. Each patient was thoroughly screened before the MRI procedure (i.e. no pacemaker, aneurysm clips, etc.) to determine whether they could safely undergo MRI. None of the volunteers had a history of any problem with the tympanic membrane or middle ear. One hundred and twenty-six (126) patients who had been referred for MR imaging of the brain were studied. Each patient was made to sign a consent form on their own volition.

All patients were clothed in hospital gowns before the scanning procedure. The digital clinical thermometer was inserted into the right external auditory canal in all the patients. The probe tip was held in this position until the temperature stabilised. The pre-scan tympanic temperature was read and recorded and patients were taken into the magnet room for scanning. As per routine operation, the magnet rooms were kept at temperatures between 15 °C-18 °C and 18 °C-20 °C for Centres A and B respectively. Similarly, the relative humidity values were 50% and 70% at Centres A and B respectively. A contrast of Gd-DPTA was given via a small intravenous line placed in a vein in the arm during the scan. Post-scan tympanic temperature was immediately measured in the same ear at the end of the scan and was recorded. Patient's age, weight, height, gender, body mass index (BMI) and total scan duration were also measured and recorded. The BMI was calculated as:

$$BMI = \frac{Weight}{Height^2} (kgm^{-2}) \quad (1)$$

Some scanning parameters: repetition time (TR), echo time (TE), specific absorption rate (SAR) and scan acquisition time for each sequence were recorded from the control panel of the MRI system as the patient underwent the examination.

3. Results

3.1 Clinical Characteristics of the Samples Investigated

One hundred and twenty-six (126) patients were used for this study. Out of this number sixty-five were males. Table 1 shows the results from the experimental data.

Table 1: Clinical Characteristics for the study

Parameters	Centre A		Centre B	
	Mean	Range	Mean	Range
Age (years)	49.90	5 – 86	47.66	10 – 80
Height (metre)	1.65	1.1 – 1.90	1.66	1.11 – 1.91
Weight (kg)	78.31	21 – 120	79.94	27 – 114
BMI (kgm ⁻²)	28.50	14.34 – 40.75	27.82	18.64 – 47.8
Scan Time (minutes)	3.87	3.27 - 5.13	5.87	5.67 – 5.97
Scan Duration (minutes)	30.68	23 – 40	41.58	30 – 51
SAR (Wkg ⁻¹)	1.25	0.4 – 1.6	0.10	–
TB (°C)	36.50	36.0 – 37.3	36.38	36.0 – 36.9
TA (°C)	36.99	36.1 – 37.8	36.75	36.1 – 37.9
ΔT (°C)	0.50	0.1 – 1.3	0.37	0.1 – 1.1

Legend:Gender (M/F): 30/34; 35/29 from Centre A and B respectively, Abbreviation: BMI = body mass index, SAR = specific absorption rate, TB = Pre-scan tympanic temperature, TA = Post-scan tympanic temperature, ΔT= change in pre- and post-tympanic temperatures

3.2 Comparison of Specific Absorption Rate (SAR) with Standards

The SAR describes the potential for heating of the patient tissue due to the application of RF energy necessary to produce the MR signal. The SAR values as illustrated in Table 2 show an agreement when compared to [5].

Table 2: Scan time and SAR compared with USFDA value used in MRI brain scan

Imaging Centres	Scan Protocol	TR (ms)	TE (ms)	Scan Time	SAR Wkg ⁻¹	USFDA
				(min)		Wkg ⁻¹
A	T2W_TSE Tra	4443	100	3.6	1.4	3.2
	T1W_TSE Tra	596	15	3.3	1.6	3.2
	FLAIR_Long TR	11000	2800	5.1	0.4	3.2
	T1W_TSE Sag	596	15	3.3	1.6	3.2
B	T2 TRS	4500	100	5.7	0.1	3.2
	T2 TRS	400	15	6.0	0.1	3.2
	FLAIR	11000	100	5.6	0.1	3.2
	T1 COR	400	15	6.0	0.1	3.2

Abbreviation:T2W_TSE Tra = Transverse relaxation weighted and turbo spin echo in transverse, T1W_TSE Tra = Longitudinal relaxation weighted turbo spin echo in transverse, T1W_TSE Sag = Longitudinal relaxation weighted turbo spin echo in sagittal, FLAIR_Long TR = Fluid attenuated inversion recovery with long repetition time, T2 TRS = Transverse relaxation in transverse, T1 TRS = Longitudinal relaxation in transverse, T1 COR = Longitudinal relaxation in coronal.

3.3 Temperature Rise

The tympanic scan temperatures of patients from Centre A increased in about 98% of the 62 patients who underwent the MRI procedure. The largest increase in temperature from Centre A was 1.3 °C in a 24 minutes scan. The tympanic scan temperatures of the patients from Centre B increased in 95.31% of the 64 patients who were used for the study. The patient with the largest increase in temperature from Centre B was 1.1 °C in a 35 minutes scan.

3.3.1 Regression Analysis

Figure 1 show a correlation graph which indicates that there is a linear relationship between the response variable (i.e. pre-scan temperature) and the predictor (i.e. post-scan temperature). A value of 0.462 was used to measure the goodness of the fit.

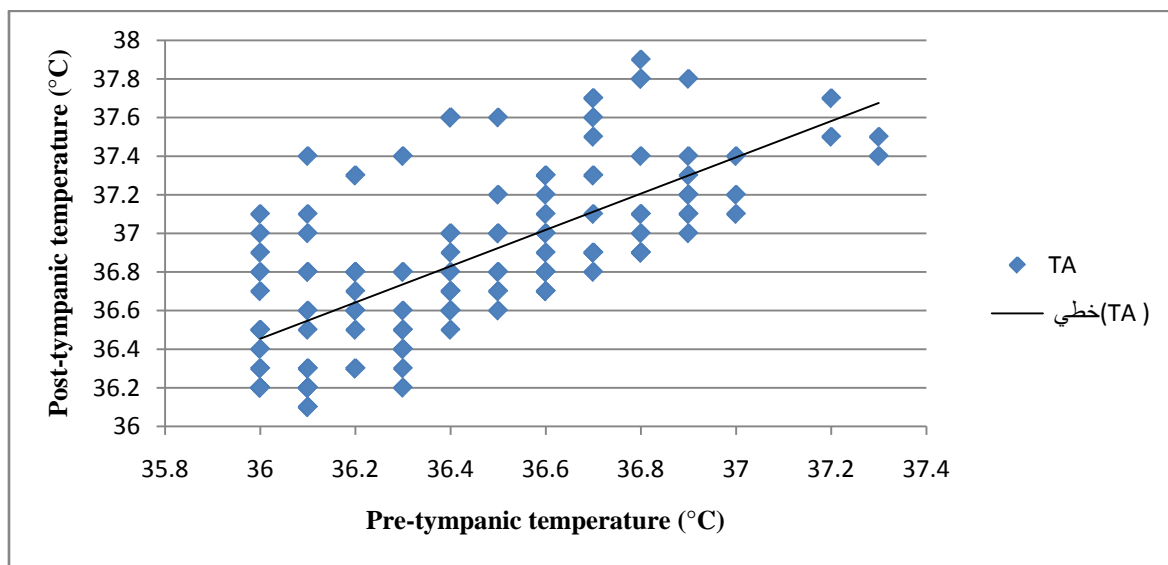


Figure 1: Relationship between pre- and post-tympanic scan temperatures

3.3.2 Relationship between Temperature Rise and Body Mass Index (BMI)

Table 3 shows the average BMI adapted from World Health Organization (WHO) with corresponding change in temperature. The World Health Organization classifies the BMI according to the following cut-off points: <18.50 kgm⁻² underweight; 18.50-24.9 kgm⁻², normal range; ≥25.00 kgm⁻², overweight and ≥30.00 kgm⁻², obese [6]. BMI values are age independent and the same for both sexes.

Table 3: The average body mass index for all patient for brain MRI scan

Imaging Centre	Ranges (kgm^{-2})	No. of Patient	Age (year)	BMI (kgm^{-2})	Scan Duration (min)	ΔT ($^{\circ}\text{C}$)
A	<18.50	3	30.67	15.91	31.0	0.3
	18.50-24.99	11	44.00	22.23	31.2	0.4
	≥ 25.00	20	47.95	27.37	30.3	0.6
	≥ 30.00	28	55.68	33.11	30.6	0.5
B	<18.50	-	-	-	-	-
	18.50-24.99	17	49.71	22.46	40.8	0.4
	≥ 25.00	25	42.60	27.34	41.5	0.3
	≥ 30.00	22	51.82	34.30	42.1	0.3

4. Discussion

All the patients from both Centres underwent the same scanning protocols with the results shown in Table 1. The results showed that patients at Centre A recorded a higher average change in temperature of 0.5 ± 0.1 $^{\circ}\text{C}$ with field strength of 1.5 T compared with those at Centre B with a value of 0.4 ± 0.1 $^{\circ}\text{C}$ with field strength of 0.3 T. The average change in temperature therefore confirms that, there is a proportional relationship between the amount of energy deposited in the body by radiofrequency (RF) field. The energy deposited is therefore significantly greater for high field scanners. Similar result was obtained by [7]. The results also show that, as MR field strength increases, so do the longitudinal relaxation time (T1), RF energy deposition in the patient, permitting higher resolution, faster scanning and increased safety concerns. This result is similar to that of [8] who drew the same conclusion and also by [9] in their book. Although there was statistically significant increase in temperatures reported in this study, none of these are physiologically deleterious. The values of the pre- and post-scan tympanic temperatures were all within guidance levels except a few of them (about 7.94% of the total number of patients) which did rise by more than 1.0 $^{\circ}\text{C}$ rise and not greater than 38 $^{\circ}\text{C}$ in the head (brain) for patients undergoing MRI procedure, according to the guidance limit set by ICNIRP for core temperatures.

The specific absorption rate of the MRI scanner depended upon the type of sequence pulse used, the repetition time and the type of transmitter RF coil used. The FLAIR scan protocol recorded the highest TR and TE values for both centres which are the two most important parameters of pulse sequence. From Centre A, the protocols with the highest SAR values were T1W_TSE Tra and T1W_TSE Sag. They both recorded 1.6 Wkg^{-1} at 3.3 minutes. The FLAIR_Long TR protocols recorded the lowest SAR values of 0.4 Wkg^{-1} at 5.1 minutes. From Centre B, the SAR values were constant for all the scan protocols with the highest time recorded by T2 TRS and T1 COR protocols at 6.0 minutes (Table 2). It is evident from the reported values in Table 2 that the SAR values for all the protocols were relatively low as compared with the standard of 3.2 Wkg^{-1} for head MRI in an average time of 10 minutes set by the USFDA. The scanner gave a constant value for all patients examined in all the protocols for all ages and gender. The variation can be attributed to operator manipulation of the number of signals averaged (NSA) during scan and in effect the acquisition time. Hence, the lower the scan time the higher the SAR value as observed from Centre A.

Figure 1 shows majority of the patients who underwent the MRI brain scan from the two Imaging Centres had an increase in temperature of 0.2 $^{\circ}\text{C}$ in 41.7 and 34 minutes average scan durations of field strength of 0.3 T and 1.5 T respectively. It was realized from Centre A that, the higher the change in temperature the lower the scan duration. Therefore, patients with increased change in temperature greater than 1.0 $^{\circ}\text{C}$ experienced shorter scan duration as compared to the values less than 1.0 $^{\circ}\text{C}$ change in temperature. Although younger age, lower body weight and longer scan duration might seem to be likely risk factors for heating, there was no relationship between these factors and increased temperature during MRI from this study. Linear regression showed a significant relationship between pre- and post-scan temperatures as shown in Figure 1. Overall, pre-scan temperature explained 46% of the total

variation of the post-scan temperature. The estimated regression model which gave a relationship between pre- and post-tympanic temperatures as:

$$y = 0.9397x + 2.6246 \quad (2)$$

where, y = Estimated post-scan temperature, x = pre-scan temperature.

In Ghana, this is the first study that has been carried out among adult volunteers undergoing MRI examination of magnetic field strengths of 0.3 T and 1.5 T. The results in this study show an increase of tympanic temperatures of 0.4 °C and 0.5 °C for 0.3 T and 1.5 T scan respectively. This increase in tympanic temperature may not pose any potential health hazard to the patient since it is well below the recommended guidance levels set by the [10, 5] standards. The World Health Organisation has recommended classifications of body-weight associated with increased health risk. These classifications are based on body-mass index, calculated as weight in kilograms divided by height in metre squared (kg/m^2). From Table 3, the average maximum change in temperature was 0.6 °C with BMI of 27.37 kg/m^2 , an average age of 47.95 years and scan duration of 30.3 minutes from 37 Military Hospital. The minimum average change in temperature was 0.3 °C which is about 40% of the total number of patients who were studied. Patients with their BMI higher than 30.00 kg/m^2 from Diagnostic Centre Limited had the highest scan duration of 42.1 minutes. The body mass index from this study shows that majority of the patients from Centre B were overweight with an average change in temperature of 0.3 °C while Centre A had majority of its patients being obese with a change in temperature of 0.5 °C. The results obtained from this work did not show significant correlation between the body mass index and the temperature increase in the brain. It is clear from this study and other studies that, the increase in temperature depends significantly on the strength of the magnet, the SAR values and the scan duration.

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