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Monitoring SAR Metrics and Physiological Thermal Changes During Fetal Magnetic Resonance Imaging at 3T

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Abstract:

- ***Background:***

Monitoring SAR and body temperature changes during 3T MRI is crucial for fetal safety. Specific Absorption Rate (SAR), which measures energy absorbed by tissues and could potentially induce heating in pregnant patients. This study estimates SAR values in fetal MRI exams and correlates them with maternal temperature changes pre and post scan to assess thermal safety at 3.0 Tesla.

- ***Methods:***

This prospective study involved 50 pregnant patients with gestational periods from 20 to 36 weeks who were referred for fetal MRI at 3.0 Tesla. The Mean SAR values ,the Pre & Post Scan body temperature changes and along with scan time per sequence per study were estimated, and analyzed for potential correlations.

- ***Results:***

The ANOVA test was performed the mean SAR was 1.3 W/kg, with a pre and post scan temperature of 98.2°F and 97.3°F indicating ($p \geq 0.05$) no statistically significant correlation between SAR values with respect to weight and temperature . The data based on total scan time while performing all three sequence, the result showed statically significance ($p \leq 0.05$) ,only with the SAR value but not with the temperature difference($p \geq 0.05$) .

- ***Conclusion:***

The current study HASTE sequences show higher SAR and involving minimal influence on whole-body temperature in fetal MRI. This study suggests MR technologists should apply SAR reducing strategies to limit scan time, ensuring safe and efficient fetal imaging at 3.0 Tesla.

Keywords: *Specific Absorption Rate (SAR), Specific Energy Dose (SED), Half Fourier Acquisition Single Shot Turbo Spin Echo (HASTE).*

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I. INTRODUCTION

Magnetic Resonance Imaging (MRI) has become a broadly utilized diagnostic imaging tool in prenatal care, allowing detailed visualization of fetal anatomy and potential abnormalities without the risk of ionizing radiation [1]. High Field MRI, like 3.0 Tesla, is increasingly used in fetal imaging due to its enhanced resolution and signal-to-noise ratio and better assessment of fetal structures and pathologies. However, this increased field strength has also added concerns regarding the Specific Absorption Rate (SAR), an important parameter indicating the rate at which radiofrequency (RF) energy is being absorbed by tissues. SAR values are expressed in units of Watts per kilogram (W/Kg) [2]. SAR values are proportionate to the precessional frequency of hydrogen protons for a given magnetic field, higher the field strengths, the greater will be the RF energy deposited and the potential heating in biological tissues, posing theoretical risks to maternal and fetal health [3].

In MRI, Various pulse sequences impact SAR levels uniquely. One such sequence is the Half-Fourier Acquisition Single-Shot Turbo Spin Echo (HASTE), which uses larger RF pulses for tissue magnetization manipulation, resulting in higher SAR and potentially greater tissue heating. On the

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contrary, the Gradient Echo (GRE) and the Diffusion-Weighted Imaging (DWI) sequences employ smaller RF pulses, depositing less RF power, leading to lower SAR and reduced heating [4]. Henceforth, understating the SAR profile of each sequence plays a vital role in ensuring patient safety, particularly in vulnerable populations like pregnant patients, where any temperature raise could possibly affect patient safety.

Previous studies show that SAR levels are proportionate to the magnetic field strengths, and tend to increase with higher field strengths. Thermal effects are often localized to the region of interest rather than affecting whole-body temperature [5]. Nevertheless, safety guidelines by regulatory bodies such as the FDA set SAR limits to prevent significant heating, recommending that Whole-body SAR to be kept within 4W/kg. However, MRI systems display SAR values with minor inaccuracies, providing only estimates rather than accurate measures of RF energy deposition [6]. Acknowledging the relationship between SAR values and any resultant body temperature changes could help MRI technologists in reducing potential risks through modified protocols.

The Current study was planned as a prospective evaluation of SAR values and their correlation with body temperature in pregnant patients undergoing fetal MRI at 3.0 Tesla. HASTE, GRE, DWI sequences were worked with body matrix or AIR coils, and SAR values were recorded for each sequence. The Pre-scan and Post scan body temperatures of the patients were measured to assess any thermal effects from the MRI exam. The main objective was to demonstrate whether SAR values that are within the FDA limits could lead to a significant increase in body temperature, indicating any potential safety risks.

Moreover, this study discusses SAR-reducing strategies for Fetal MRI, such as minimizing the number of acquisitions, optimizing the sequence parameters, managing scan times, which are essential to limit RF energy exposure and reduce tissue heating. Our findings provide understanding into the practical considerations of high-field MRI for fetal evaluation and highlight the importance of protocol adjustments to maintain safety in routine clinical practices [3,7].

II. METHODS

- *Study Population:*

The study was approved by the institutional ethical committee (IEC) (CSP/23/MAR/125/233). A Prospective data of 50 pregnant patients for a period of March 2023 – July 2023 who were referred for fetal MRI examinations were included in this study.

- *Inclusion Criteria:*

All pregnant women with either suspected or detected fetal anomalies diagnosed on ultrasound. Pregnant patient with strong history of previous pregnancy with congenital fetal abnormality or familial history of congenital fetal anomalies with sonographically occult diagnosis.

- *Exclusion Criteria:*

First trimester pregnancy (For the completion of organogenesis.).

- *Legal Documentation:*

Informed consent with fully filled forms as per the "Pre Conception and Pre Natal Diagnostics Techniques (PCPNDT)" were obtained for all exams. This was a Prospective study which was presented over pregnant patients who were referred for fetal examinations performed at 3.0 Tesla MRI at 128 MHz using body matrix coil or AIR coil, by employing HASTE, Gradient echo and Diffusion weighted sequences. Only one set of DWI and GRE were acquired but whereas multiple acquisition of HASTE were performed in several oblique planes which varied on an individual basis pertaining to clinical indications and differential diagnosis. The minimum number of HASTE acquisition was 9 and a maximum of 30 in this data of 50 fetal MRI examinations. However, this multiple acquisitions were necessary to yield sufficient information for radiological interpretation and differential diagnosis to enable appropriate patient management.

The body weight and the body temperature of the patient was monitored using a digital thermometer before the exam, the patients were screened and prepared as per MRI norms and were positioned on the MRI table. Routine sequences such as Spin echo sequences, Gradient echo sequences and Diffusion weighted sequences were performed by using following parameters: SSFSE (2000/130; flip angle, 180°), T1-weighted SPGR (200/10; flip angle, 60°), and EPI - DWI (4800/46; flip angle, 90°). The field of view (range, 200–400 mm) and section thickness (range, 3–10 mm) remained constant. Images were obtained sequentially in three planes (axial, coronal, and sagittal) relative to the fetal anomaly.

Multiple acquisitions were made based on patient's correspondence and fetal movement, the total number of sequences performed and the respective SAR value for each sequence were noted. After completion of the study, the patient's body temperature was once again monitored by using a digital thermometer and noted. the post scan temperatures were compared with the pre scan temperature and the temperature difference was calculated .The total mean SAR value of individual pulse sequence like T2W SSFSE/HASTE, T1W SPGR, DWI were calculated by averaging repeated sequences separately with respect to patient's body weight and total scan time, and the mean value is obtained.

The overall mean SAR value for each patient per study is calculated by averaging the SAR values of all three pulse sequences such as T2W SSFSE/HASTE, T1W SPGR, DWI depicted for the whole study with respect to patient's body weight and the total scan time, the mean SAR value for the whole study is obtained. The obtained mean values were statistically analyzed to evaluate any increase in SAR value and it's corresponding increase in body temperature of pregnant patients.

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➢ *Statistical Analysis:*

Demographic information, measurement data, and clinical characteristics (such as maternal age, gestational age, and fetal weight) were reported as mean ± standard deviation. To evaluate the correlation between SAR values , maternal body temperature and scan time were analyzed using one-way ANOVA to identify any statistically significant variations between sequences. For post-hoc comparisons, Tukey's test was used to pinpoint specific differences when ANOVA showed significance. Paired t-tests were also conducted to compare pre- and post-scan temperature values. Statistical significance was set at $p < 0.05$ for all analyses. All statistical analyses were performed using SPSS statistical software version 22.0.

III. RESULTS

The prospective study on the evaluation of Specific Absorption Rate (SAR) values in fetal MRI included data of 50 studies. The age of the women who underwent fetal MRI varied from a minimum of 20 years to a maximum of 42 years with a mean of 28 years. The gestational period of patients were from as early as 20 weeks to 36 weeks of gestation. The maternal weight varied from a minimum of 52 kg to a maximum of 83 kg with a mean of 67 kg (Table 1,2).

The statistical analysis of SAR values based on patient weights were not significant (Table 5) as the SAR deposition on each patient's weight category differed, but the statistical analysis of SAR values based on patient scan time were significant and were inversely proportional, as the scan time increased the SAR value decreased, the temperature difference shows insignificance as the mean post scan temperature is comparatively lesser than the mean pre scan temperature of the patient (Table 4) .

The mean SAR deposited to the pregnant mother while performing HASTE sequence varied between a minimum of 2.11 W/kg and a maximum of 2.72 W/kg with an average SAR of 2.36 W/kg. Whereas the mean SAR deposited to pregnant mother while performing Diffusion weighted sequence varied with minimum of 0.21 W/kg and maximum of 0.85 W/kg with an average SAR of 0.48 W/kg (Table 1).

The mean SAR deposited to the pregnant mother while performing SPGR sequences varied between a minimum of 0.7 W/kg and a maximum of 1.85 W/kg with an average SAR of 1.16 W/kg. Whereas the overall mean SAR deposited to pregnant mother's for the whole study including all the three pulse sequences ranged 1.3 W/kg (Table 3). The overall mean body temperature of the pregnant patient prior to the scan was noted to be 98.2 °F, and the overall mean body temperature, post scan was noted to be 97.9 °F (Table 4 & 5).

It was observed that the SAR values were more in HASTE sequences when compared to SAR values in Diffusion weighted imaging and Gradient sequences. On statistical analysis, evaluating the data based on patient weight, the result showed no significance as weight of the patient doesn't seemingly manipulate the change in SAR or temperature of the patient, but on evaluating the data based on total scan time, the result showed significance ,only with the SAR value but not with the temperature difference, as the overall average SAR value is 1.3 W/kg with an average post scan temperature of 97.3 °F and an average pre scan temperature of 98.2 °F (Table 5), showing no rise in temperature. The results suggest that SAR exposure values were well within the recommended limits for whole body exposure as per FDA guidelines

IV. DISCUSSION

Specific Absorption Rate (SAR)) is an important parameter that refers to the amount of Radiofrequency power delivered to the patient, expressed in watts per kg (W/kg). The radiofrequency energy deposited varies based on the precessional frequency of the Hydrogen proton for a given magnetic field strength. The amount of tissue heating depends on the magnitude of the RF pulse and the frequency of the RF pulses applied (1). HASTE, basically a Spin echo sequence uses a large RF pulses for the 90^0 and 180^0 manipulation of tissue magnetization. As a result, HASTE delivers more RF power resulting in higher SAR and relatively more tissue heating(3). Whereas, GRE sequence uses much smaller RF pulses, less RF power deposited resulting in lower SAR and less tissue-heating.

Christian A Barren et.al., (4), reported that mean SAR at 3.0 T (1.25 W/kg ± 0.54, respectively; and mean SED 3.0 T (39 J/kg ± 24) in fetal body MR (4)(5). In this study, HASTE sequence was found to deposit higher SAR and therefore, more tissue heating when compared to the DWI and GRE sequence. Also, SAR values increase with increase in number of sequences. Based on the study by Christian A Barren(4), to compare the specific absorption rate (SAR) and specific energy dose (SED) of fetal MRI at 1.5T and 3.0.T the results of the examinations were found to have equivalent energy metrics in most cases, inclusive of SAR values at 3.0 Tesla(5).On comparing the Average SAR value of HASTE, GRADIENT, DIFFUSION sequences separately categorised by weight, along with temperature difference, the correlation showed insignificance, since most SAR values differed with increase or decrease in weight, because the total scan time of the patient played a major role, though insignificant the overall SAR value for the three pulse sequences remained within the normal limit with no rise in body temperature. Also our study comparing the average SAR value of all three sequences separately categorised by patient scan time, along with temperature difference, the correlation was significant, as the scan time increases, the SAR value of each pulsative sequence decreased, the increased scan time is due to the increased number of repeat factors for each sequences and scan time . HASTE sequence is a T2 weighted sequence requiring a longer TR & longer TE for comprehensive image quality(1), due to the increased TR value, the sequence scan time increases, thus increasing the overall scan time, due to the effect of longer TR, the time interval from applying the first RF to the second RF pulse is increased, this increased TR interval would cause dissipation of RF deposition of the previous RF

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pulse, dissolving it's effect over the second RF pulse, due to it's rapid dissipation, the heating effect of RF is neglected and the overall SAR value is decreased.The scan time has minutely manipulated for the change in temperature though, because as the scan time increases, the temperature difference is more prominent, as seen in the correlation. Out of 50 samples, though a few patient's showed a 0.2-0.4 ^{0}F temperature rise, it couldn't be concluded as a cause of RF heating due to a very negligible variance. Most of the cases showed a comparatively broader decrease in temperature after the study ranging from 0.3-1.0 ^{0}F, only assuming the cause could be the external magnet room ambience. Possibilities for any rise in temperature could be expected only when SAR level could reach a minimum of 4W/kg, our study attempted in tracing out any minute temperature rise even at any least random fluctuation of SAR deposition, possibly much lesser than 4W/kg, to calculate the proportionality of SAR and temperature, based on the values obtained from current samples, the SAR values which are kept within the recommended limits(6), has a very least influence over the whole body temperature, provided the heating effect could be suspected at a very localized region or only at the region of interest, if not noted or depicted in the whole body temperature.

Nevertheless, it is mandatory to monitor the patients during scan acquisition by establishing two way communication, because increased RF exposure are associated with various physiological effects like visual and auditory disturbances, altered endocrine, neural, immune and developmental function. Our attempt to calculate the proportionality of SAR and temperature, based on the values obtained from current samples, the SAR values which are kept within the recommended limits, has a very least influence over the whole body temperature, provided the heating effect could be suspected at a very localized region or only at the region of interest, if not noted or depicted in the whole body temperature. Our results suggest that SAR exposure values were well within the recommended limits for whole body exposure as per FDA guidelines.

V. CONCLUSION

In this study suggested that HASTE sequences show higher SAR in fetal MRI but remain within FDA limits, involving minimal influence on whole-body temperature. MR technologists should apply SAR-reducing strategies and optimize protocols to limit acquisitions and scan time, ensuring safe and efficient fetal imaging at 3.0 Tesla

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TABLES

Table 1 Patient Age and Weight Distribution Table

	Minimum	Maximum	Mean
Age	**20 years**	**42 years**	**28 years**
Maternal Age	**20 weeks**	**36 weeks**	**24 weeks**
Weight	**52 kg**	**83 kg**	**67 kg**
Sequence SAR value and Temperature distribution			
T2 SSFSE/HASTE	**2.11 W/kg**	**2.72 W/kg**	**2.38 W/kg**
T1 SPGR	**0.7 W/kg**	**1.85 W/kg**	**1.16 W/kg**
DWI	**0.21 W/kg**	**0.85 W/kg**	**0.48 W/kg**
Temp© - Pre scan	**97.3 F**	**98.6 F**	**98.2 F**
Temp© - Post scan	**96.4 F**	**98.6 F**	**97.9 F**

Table 2 ANOVA Test on Correlating SAR value with Respect to Weight & Temp©Difference

		Sum of Squares	df	F	Sig.
HASTE SAR (W/Kg)	Between Groups	.076	3	.734	**.537**
	Within Groups	1.595	46		
	Total	1.672	49		
DIFFUSION SAR	Between Groups	.008	3	.067	**.977**
	Within Groups	1.800	46		
	Total	1.808	49		
GRADIENT SAR	Between Groups	.125	3	.516	**.673**
	Within Groups	3.723	46		
	Total	3.848	49		
Overall SAR	Between Groups	.044	3	.354	**.786**
	Within Groups	1.915	46		
	Total	1.960	49		
Temp_diff	Between Groups	.628	3	.797	**.502**
	Within Groups	12.088	46		
	Total	12.717	49		

Table 3 ANOVA Test on Correlating SAR value with Respect to Time & Temp©Difference

		Sum of Squares	df	F	Sig.
HASTE SAR (W/Kg)	Between Groups	1.109	3	30.228	**.000**
	Within Groups	.563	46		
	Total	1.672	49		
DIFFUSION SAR	Between Groups	1.267	3	35.965	**.000**
	Within Groups	.540	46		
	Total	1.808	49		
GRADIENT SAR	Between Groups	3.072	3	60.686	**.000**
	Within Groups	.776	46		
	Total	3.848	49		
Overall SAR	Between Groups	1.710	3	104.855	**.000**
	Within Groups	.250	46		
	Total	1.960	49		
Temp_diff	Between Groups	.482	3	.605	**.615**
	Within Groups	12.234	46		
	Total	12.717	49		

Table 4 Mean value Chart Categorized upon Total Scan Time

TIME (mins)	**HASTE**			**DIFFUSION**			**GRADIENT**			**Avg.Temp (F)**		
	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	PRE - SCAN	POST - SCAN	Overall SAR (W/Kg)
30 - 39	2.48	2.72	2.62	0.61	0.85	0.75	1.25	1.85	1.56	98.2	97.9	1.64

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40 - 49	2.26	2.68	2.4	0.29	0.68	0.51	1.08	1.45	1.24	98.2	97.9	1.38
50 - 59	2.13	2.53	2.25	0.27	0.75	0.4	0.78	1.17	1	98.3	98.02	1.21
60 & Above	2.11	2.42	2.2	0.21	0.35	0.27	0.7	1.02	0.85	98.3	97.8	1.1
Overall Average										98.2	97.9	1.3

Table 5 Mean value Chart Categorized upon Patient's Weight

WEIGHT (Kgs)	**HASTE**			**DIFFUSION**			**GRADIENT**			**Avg.Temp (F)**		
	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	Min.SAR (W/Kg)	Max. SAR (W/Kg)	Mean SAR (W/Kg)	PRE - SCAN	POST - SCAN	Overall SAR (W/Kg)
50 – 59	2.13	2.53	2.3	0.23	0.78	0.47	0.7	1.34	1.12	98.2	98.1	1.3
60 -69	2.11	2.68	2.4	0.21	0.78	0.49	0.71	1.85	1.15	98.2	97.8	1.35
70 – 79	2.14	2.72	2.34	0.25	0.85	0.47	0.77	1.78	1.15	98.2	98.04	1.32
80 – 89	2.27	2.65	2.41	0.35	0.68	0.51	1.14	1.65	1.32	98.4	98.05	1.34
Overall Average										98.2	97.9	1.3