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Evaluation of Specific Absorption Rate due to Medical Implant in Near-Field Exposure

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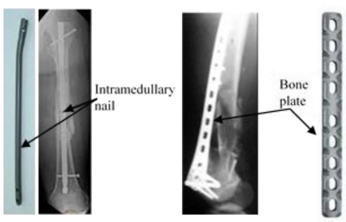
Graphical abstract



Abstract

This paper presents the effects of conductive medical implant on energy absorbed by the human body and the testicular area when exposed to near field electromagnetic radiation. A dipole antenna is used as the radiating source and it is placed in front of the trousers pocket. Two types of medical implants are used in this study: intramedullary nail and bone plate. Numerical simulations are performed by means of CST Microwave Studio. Results are discussed in terms of changes in SAR values due to the presence of conductive medical implant at 0.4, 0.9, 1.8 and 2.4 GHz. The results have indicated that the conductive intramedullary nail that is located inside the femur significantly increases the SAR. Maximum enhancement in SAR is found when the length of the intramedullary nail is approximately one wavelength of the respective frequency tested. The measurement results indicate good agreements with the simulation results at 2.4 GHz.

Keywords: SAR (Specific Absorption Rate); electromagnetic wave; conductive medical implant; energy absoprtion

Abstrak

Kajian ini membentangkan kesan penggunaan implan dalam bidang perubatan yang bersifat konduktif terhadap penyerapan tenaga oleh tubuh badan dan testis apabila terdedah kepada radiasi elektromagnetik. Antena *dipole* digunakan sebagai sumber radiasi dan diletakkan dikawasan poket seluar sebagaimana keadaan telefon bimbit diletakkan di dalam poket seluar. Dua jenis implant yg digunakan dalam bidang perubatan digunakan dalam kajian ini: *intramedullary nail* dan *bone plate*. Simulasi dijalankan dengan menggunakan *CST Microwave Studio*. Keputusan dibincangkan dalam konteks SAR pada empat frekuensi berbeza iaitu 0.4, 0.9, 1.8, dan 2.4 GHz. Keputusan telah menunjukkan bahawa rod yang bersifat konduktif berupaya meningkatkan kadar penyerapan tenaga (SAR) oleh tubuh badan sehingga berkali ganda jika dibandingkan dengan keadaan tiada implan. Peningkatan maksima diperolehi apabila panjang rod yang digunakan menghampiri panjang gelombang pada frekuensi tertentu. Keputusan ujikaji menunjukkan persamaan dengan hasil simulasi pada frekuensi ujikaji 2.4 GHz.

Kata kunci: SAR (Specific Absorption Rate); asas risiko; aloi tahan kakisan (CRA); pintu keputusan; hakisan karat; prestasi kitaran hidup paip

1.0 INTRODUCTION

In recent years, the usage of mobile handset unit has increased tremendously. Therefore the user has become concerned and subject of recent interest on any possible health effects due to the mobile phone radiation. The exposure standard for mobile devices employs a unit of measurement known as the *Specific Absorption Rate* (SAR). SAR is a measure of the amount of energy absorbed by the body when exposed to a *radio frequency* (RF) electromagnetic field a unit. Maximum permissible exposure limits to the RF energy have been set by several experts' organizations via SAR values. Most standards (FCC and IEEE) set the SAR limit to 2 W/kg over 10 g mass of tissue. The SAR is calculated by Eq. 1:

$$SAR = \frac{\sigma|E|^2}{\rho} W/kg \tag{1}$$

|E| is the rms electric field magnitude, σ is the conductivity (S/m) and ρ is the material mass density (kg/m^3).

A mobile phone is usually placed inside the trousers pocket while connected via bluetooth connection or left in standby mode when it is not in use. Hence it is placed in very close proximity to the human sensitive organ (testicles). The antenna periodically radiated the Electromagnetic (EM) wave to retain its connectivity to the base station. Therefore the presence of additional conductive items inside the pocket may raise concerns due to their proximity to the radiating source and to the human tissues especially the sensitive organs.

At present, the interactions between the electromagnetic wave and human biological tissues have been widely investigated in [1-5]. Based on [6-10], the presence of additional metallic items could significantly enhance the total power absorbed by the human tissues. Besides, [6,11] reported that patients with implanted item potentially suffer from heating while undergo the MR procedures. In addition, authors in [7,12,13] indicate that the presence of metallic implant in tissue changes the SAR distributions. Thus higher power absorption is observed inside tissues near the metallic implant. In [7], the numerical results have confirmed that the presence of earring, fixtures, and skull plate strongly alter the maximum average SAR. Besides, the local peak SAR is found close to the tip area of the screw. In addition, authors in [14] concluded that the intramedullary nail inside the femur that is in direct contact with the soft tissue notably increases the current density up to 9.5 mAm^{-2}.

Up to date, there are very limited numbers of research that focuses on the near-filed effect of the conductive metallic implant especially in close proximity to the waist area. Moreover, most researches have been focusing on the far-field interaction on human body in the presence of medical implant. Therefore, this paper tends to highlight the effects of conductive medical implants that are implanted inside the femur on SAR at four different frequencies.

2.0 RESEARCH METHODOLOGY

2.1 Simulation Set-up

The numerical simulations are performed by using Finite Integration Technique (FIT) [12]. A λ/2 dipole antenna is used as the radiating source and placed 5 mm away from the leg of Voxel model mimicking the position of the mobile phone unit inside the front trousers pocket. Research in [15] has shown that the orientation of an implant has a major effect in its interaction with the EM field in the tissues. The absorption is evidently highest when the longest dimension of the implant and the antenna are parallel. Therefore in this study, the dipole antenna is orientated along the z-axis which is in parallel to the conductive implant. The Voxel body model used in this research consists of 32 types of human biological tissues with the dielectric properties of the model are as recommended by the FCC and IEEE.

In order to evaluate the effect of conductive medical implant, two types of medical implants are considered in this research, which are an intramedullary nail and a bone plate (as in Figure 1). In practical, these two implants are used to fix fracture in the waist area. These implants are chosen because they are usually being implanted for a few months and commonly used to treat for almost 23 fractures of the femur. The intramedullary nail (Figure 1 (a)) is modeled as simple metallic rod shape and it is implanted inside the femur, while the bone plate (Figure 1(b)) is modeled in rectangular shape. Figure 1 (c) represent the x-ray image for the real position of medical implant in patient. Both implants are given the electrical properties of stainless steel with conductivity, $\sigma = 1.35 \times 10^6$ Sm^{-1}, $\rho = 8000$ kgm^{-3} and thermal conductivity = 16.3 W/m/K.

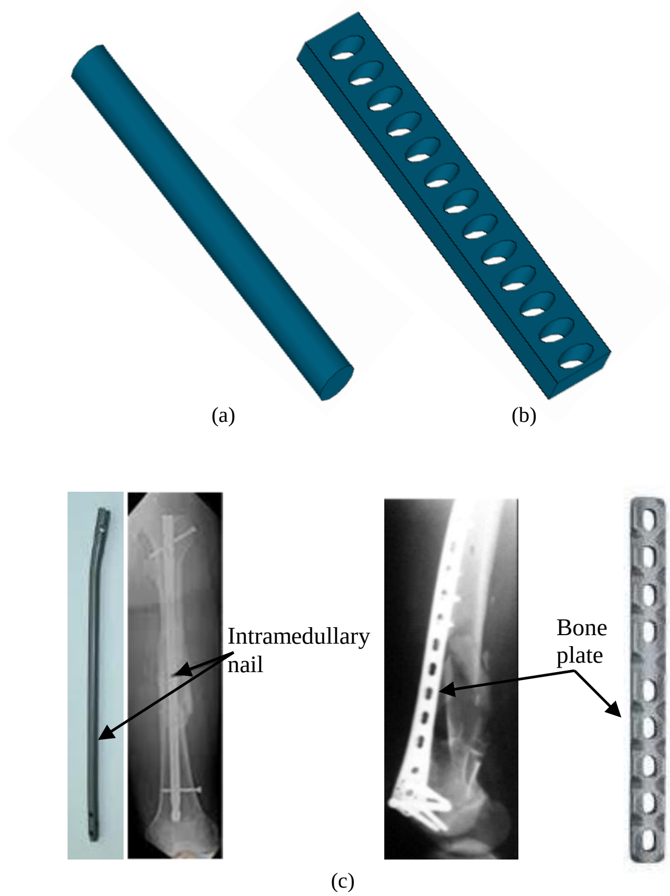


Figure 1 Simplified shape of medical implants used in the simulation (a) intramedullary nail (b) bone plate (c) exact position of implants inside the patient

Furthermore, the intramedullary nail is modeled with 10 mm of diameter, d_r with three different lengths, l_r of 167, 220, and 333 mm, whilst the bone plate is designed with the dimension of 212 mm × 16 mm × 5 mm. These sizes are chosen to coincide with the sizes available in the market. Figure 2(a) depicts the simulation setup and the position of medical implant considered in this study. The conductive rod is located inside the femur while the bone plate is attached to the femur. The implant is located at 70 mm inside the leg with respect to the skin.

2.2 Measurement Set-up

Measurement is done by using a phantom of waist area that is filled with tissue simulating liquid at 2.4 GHz. The waist phantom is made of fiberglass (thermal conductivity = 0.04 W//m/K) materials with the thickness of 3 mm and reassembles the real shape of human waist (Figure 2(b)). The equivalent liquid has the dielectric properties that is similar to the dielectric properties of average muscle as recommended by FCC (conductivity, $\sigma = 1.78$ S/m and relative permittivity, $\varepsilon_r = 53.6$). The SAR probe and the implant are placed inside the phantom and the SAR values are recorded. The distance between antenna and phantom are also varied to evaluate the effect of antenna-body distances on SAR. The index SAR probe contains of three orthogonal dipole sensors arranged on a triangular prism core and the tip is covered by PEEK cylindrical enclose material [16]. Figure 2(b) shows the measurement setup. The simulation results are compared to the measurement results at 2.4 GHz for validation purposes.

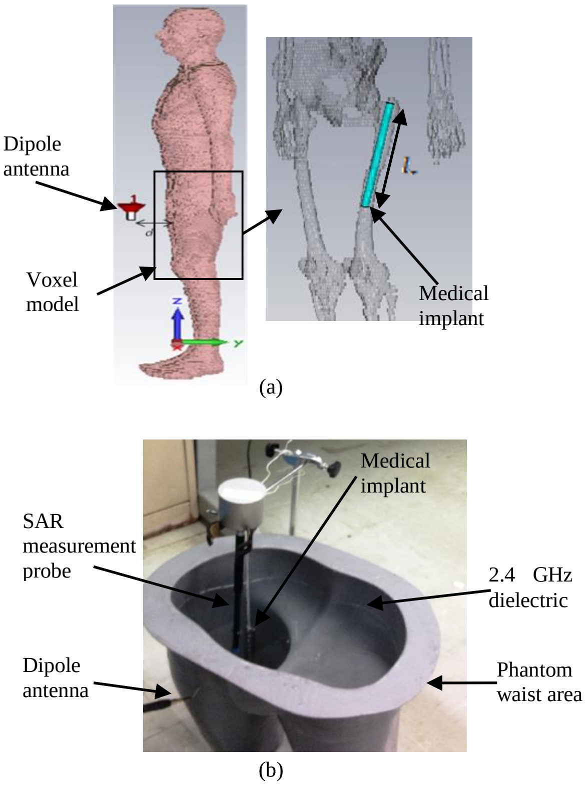


Figure 2 (a) Simulation setup and (b) measurement setup

3.0 RESULTS AND DISCUSSIONS

All simulations are computed by using CST Microwave Studio. The results are discussed in terms of energy absorption by the human body in the presence of two common types of medical implants; bone plate and intramedullary nail. For reference SAR, the human body is simulated in free space (without the metallic implant) and the excitation is provided by a half-wave dipole antenna at 0.4, 0.9, 1.8 and 2.4 GHz.

All simulations results are normalized to 1 W input power. Simulated results at 2.4 GHz are then are compared to measurement results. Table 1 summarizes the simulated maximum average 10 g SAR in the area of human waist and also inside the testicle for all cases considered in this research (with and without implant).

3.1 Effect by the Presence of Rod (Intramedullary Nail)

Results in Table 1 indicated that, the presence of rod (of all sizes) causes significant increment on the amount of energy absorbed by the biological tissues at all frequencies tested. The longest rod contributes to the highest changes of energy absorption. The presence of 333 mm rod has significantly increases the absorption from 1.4 W/kg up to 5294.33 W/kg.

At 0.9 GHz and 1.8 GHz, the 333 mm rod which length is approximately $\lambda/2$, λ and 2λ (of the respective frequency) had prominently increases the 10g SAR (as shown in Figure 3 and Figure 4). The average 10g SAR is increased by 863% from the case of without an implant attached to the femur. However, smaller increment is observed on the average 10g SAR at 2.4 GHz. This is due to the lower penetration depth of electromagnetic energy at higher frequency.

Freq. (GHz)	**Implant size (length, lr) (mm)**	**10 g SAR With implant (W/kg)**	
		Wrist Area	Testicle
0.4	Without implant	1.40	0.11
	Rod 167	1345.99	0.10
	Rod 220	1810.96	0.11
	Rod 333	5294.33	0.11
	Bone plate	53.26	0.10
0.9	Without implant	4.40	0.19
	Rod 167	566.10	0.21
	Rod 220	391.03	0.20
	Rod 333	745.94	0.21
	Bone plate	25.67	0.21
1.8	Without implant	11.69	0.14
	Rod 167	74.38	0.15
	Rod 220	71.99	0.11
	Rod 333	112.57	0.12
	Bone plate	13.63	0.10
2.4	Without implant	16.61	0.08
	Rod 167	18.08	0.06
	Rod 220	16.19	0.09
	Rod 333	14.91	0.08
	Bone plate	14.88	0.08

Table 1 The value of 10 g SAR at 0.4, 0.9, 1.8 and 2.4 GHz

In addition, the presence of conductive medical implant has notably influenced the SAR distribution inside the human body. Figure 5 demonstrates the 10g SAR distribution at four different frequencies. Without the implant, the peak SAR is generally found close to the skin surface as also for the case of the presence of the implant at 1.8 GHz and 2.4 GHz respectively. However, the energy has apparently concentrated around the rod (which is indicated by red region) when the rod is implanted inside the femur at lower frequencies (0.4 GHz and 0.9 GHz). Consequently this scenario indicates that the electromagnetic wave penetrates deep inside the body (at low frequency) and provide sufficient amount of current at the implant location. Therefore, the conductive rod tends to induce current and redistribute the energy to the surrounding tissues.

3.2 The Presence of Bone Plate

Figure 6 represents the SAR distribution inside the leg with bone plate at 0.4, 0.9, 1.8, and 2.4 Hz. It can be noted that the maximum SAR is remarkably enhanced near the edge of the bone plate. These results indicate that the presence of additional conductive implant significantly changes the SAR distribution. Sharp edge of conductive object concentrates higher current density and lead to higher energy absorption by the surrounding tissues. The numerical results of maximum average 10 g SAR in the waist area are shown in Figure 7. As expected, the maximum increment is observed at 0.4 GHz which is due to the higher penetration depth at low frequency. The presence of the bone plate could increase the SAR by 51 W/kg at 0.4 GHz. Meanwhile, slightly lower effect is observed at 0.9 GHz as the bone plate increases the SAR by 21 W/kg. However, there is no significant increment is observed at higher frequencies (1.8 and 2.4 GHz).

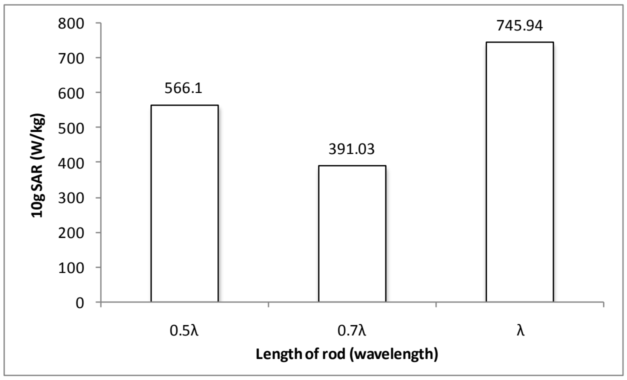


Figure 3 10 g SAR with different length of rod with respect to the wavelength at 0.9 GHz

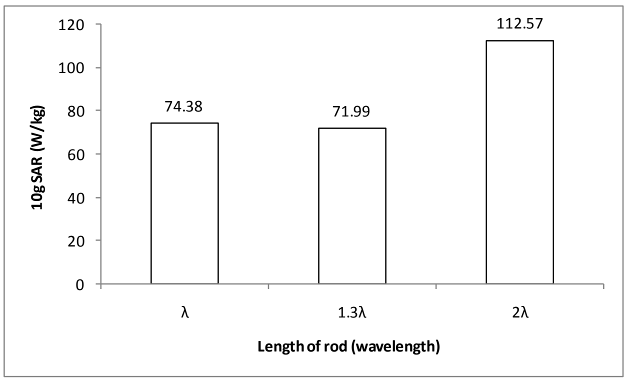
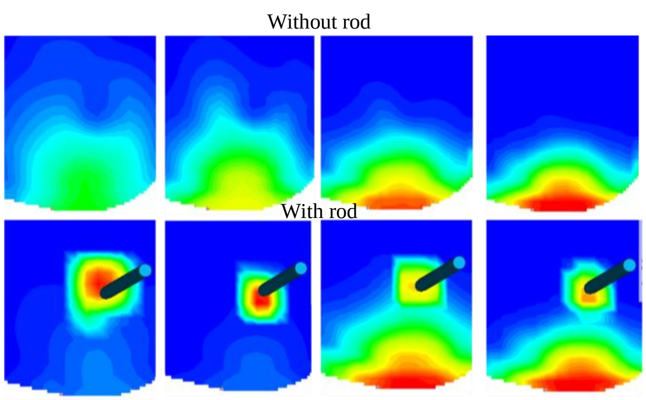
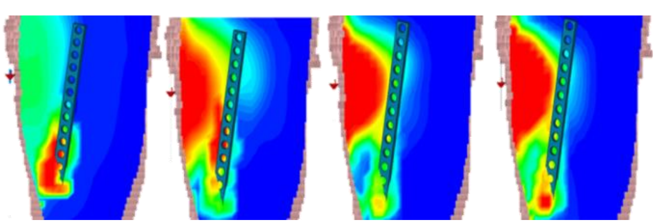


Figure 4 10g SAR with different length of rod with respect to the wavelength at 1.8 GHz



(a) (b) (c) (d)

Figure 5 SAR distributions with (bottom) and without (top) conductive implant (rod) at (a) 0.4 GHz (b) 0.9 GHz (c) 1.8 GHz (d) 2.4 GHz



(a) (b) (c) (d)

Figure 6 SAR distributions with conductive implant (bone plate) at (a) 0.4 GHz (b) 0.9 GHz (c) 1.8 GHz (d) 2.4 GHz

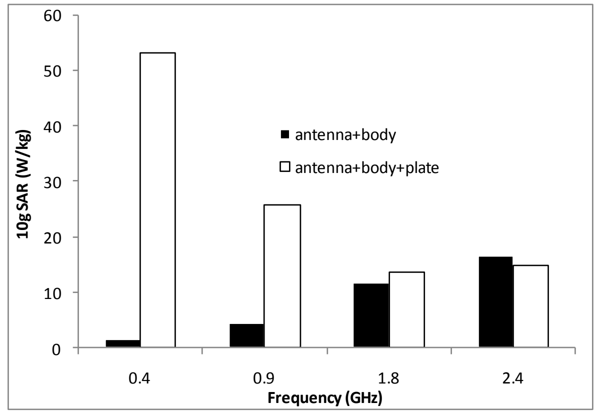


Figure 7 Comparison of 10g SAR values with and without bone plate at all simulated frequencies

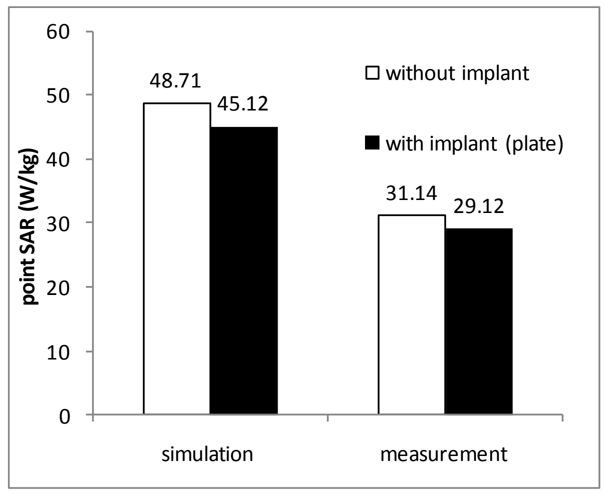


Figure 8 Simulated and measured SAR at 2.4 GHz

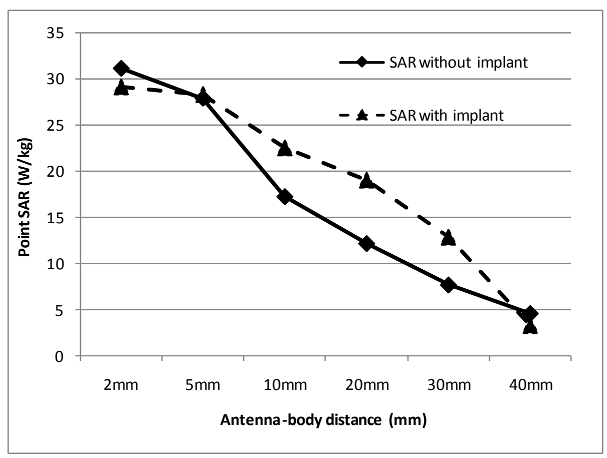


Figure 9 Measurement results of SAR in the presence of bone plate at different antenna-body distance ay 2.4 GHz

3.3 Measurement Results

Figure 8 shows the point SAR values with and without implant (bone plate) at 2.4 GHz. The results are normalized to 1 W input power. The measured result is in good agreement with the simulated results indicating more than 2 W/kg increments of 10 g

SAR due to the presence of conductive metallic implant. As expected the simulation results obtained are slightly higher than the measurement results. This may be due to the antenna-body distances during the measurement setup and also the usage the fiberglass phantom in the measurement. The fiberglass phantom includes shell thickness that may differ with the Voxel body thickness used in the simulations. In addition, the fiberglass has its conductivity which also not being considered during the simulation. Besides, the results in Figure 9 have confirmed that the SAR value is decreased as the distance between the antenna and the body is increased. As the antenna-body distance is increased, more energy is radiated towards the free space rather than being absorbed by the human tissue.

■4.0 CONCLUSION AND FURTHER WORK

This study presents the effect of conductive medical implant on SAR at four different frequencies; 0.4, 0.9, 1.8, and 2.4 GHz. The results have confirmed that the presence of medical implant has significant effect on the amount of energy absorption and SAR distribution. However, the effects vary according to the excitation frequency. The rod has significantly enhances the energy absorption by the human biological tissues at all frequencies tested. The metallic rod tends to induce high current density and act as secondary antenna that reradiates the electromagnetic waves. The maximum absorption is observed when the length of the implant is approximately one wavelength of the frequency tested.

In addition, higher increment is observed at lower frequency (0.4 GHz). This is due to higher penetration depth at lower frequency compared to higher frequency. The penetrated electromagnetic energy inside the body supplies sufficient amount of current to the conductive rod and the rod possibly redistribute the electromagnetic energy to the surrounding tissues. Thus, at higher frequencies the peak SAR is generally found close to the skin surface and inside the fat tissues. Hence, no deep penetration and concentration of energy is found in the human tissues.

On the other hand, the presence of bone plate with sharp edges notably alters the maximum absorption around its tips. This is due to the high concentration of current density close to the sharp edges. Nevertheless, the presence of medical implant does not have any prominent effect on SAR enhancement in testicle (refer to Table 1) owing to its larger distance from the antenna and the metallic implant.

This study has provides general estimation of SAR enhancement due to the presence of conductive medical implant. However in practical, other conductive items (such as external metallic objects; coin, ring or zip) may also be located in close proximity to the waist area. This condition is expected to have further effect on SAR and worth for further investigations in the future.

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