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Electromagnetic coupling mechanism in a layered human tissue model as reference for 434 MHz RF medical therapy applicators

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Introduction

In order to minimize exposure to human tissue, electromagnetic interaction with antennas has benefited from a lot of research since hand-held communication transceivers became widely used consumer products. Motivated by safety concerns, much of the literature is focused on studies using communication frequencies. On the other hand, medical applications have been exploiting the ISM (Industrial Scientific and Medical standard) 434 MHz frequency band for therapeutic applications such as hyperthermia [1]. In this case, reducing the size of the radiating applicator and efficient delivery of high powered electromagnetic energy without burning the skin (which adds to patient discomfort during the exposure) are priority considerations.

Simulated models of different geometries and layers have been used to investigate the electromagnetic absorption in human tissues. Single-layer tissue structures have been widely analyzed [2, 3] for comparison with measurement standards, but multi-layered models are more representative of actual coupling in human tissue. While full body phantoms are available, planar multi-layered tissue are more computationally efficient with standard simulation resources. Typically, reported studies have concentrated on far-field [4] or close proximity near-field illumination [5].

Various antennas have been used in hyperthermia applicators but advanced designs depend on improved knowledge of the radiated antenna modes and interacting influence of human tissue. As a preliminary step towards analyzing antennas interacting with tissues in the near- and far-fields, this study reports on the coupling mechanism of a half-wavelength dipole at 434 MHz. This will provide an experimental method for researching more suitable and efficient antennas for medical applications.

Planar layered tissue model

A planar layered tissue model was used to study the electromagnetic energy absorption. This model comprised three tissue layers (skin, fat and transverse

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fiber of muscle). The thickness sum of the three layers was fixed to 100 mm. Nine combinations of skin, fat and muscle tissue with different thickness were used to represent the absorption in the different parts of the body.

For all body regions, the skin thickness ranges between 0.4 mm and 2.6 mm [6], but in this study an intermediate skin thickness of 1.3 mm was also evaluated. In the body, the fat thickness ranges from 0 mm to 23.2 mm [7], however, this ignores obese tissue. This study extended the limit of this tissue to 30 mm and also evaluated a layer of 15 mm thickness.

The third and terminating layer of the model is representative of transverse fiber of muscle. Reflection effects of deeper tissue layers are not considered due to the high attenuation of these deep layers.

The different layers of the human tissue were modeled at 434 MHz with the dielectric parameters of permittivity, ε_r; conductivity, σ (S m^{-1}); and density ρ (Kg m^{-3}), given by the Federal Communications Commission [8] and values used in [5]. Those parameters are shown in table 1.

	ε_r	σ (S m^{-1})	ρ (Kg m^{-3})
Skin (Dry)	46.059418	0.702340	1100
Fat	5.566293	0.041669	916
Muscle (Transverse Fiber)	56.865852	0.805096	1041

Table 1. Dielectric parameters of permittivity, conductivity and tissue densities at 434 MHz.

A dipole antenna with parameters of wire length, $L = 0.47\lambda$ mm, wire radius, r = 1 mm, and feedgap, g = 1.8 mm was positioned 50 mm distant from the tissue model. The coordinate system for the dipole and layered planar tissue model is shown in figure 1.

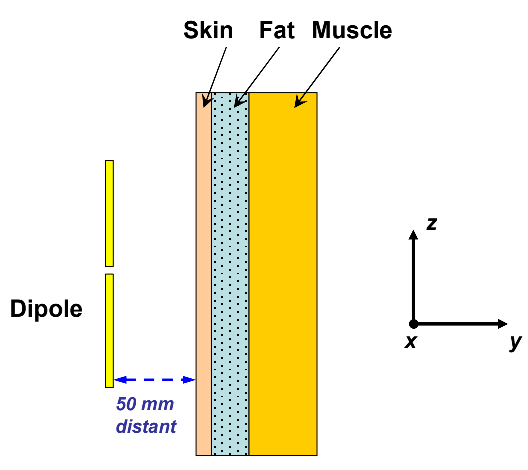

Fig. 1. Dipole-Layered planar tissue model and coordinate system.

SAR and point location of maximum SAR in the layered tissue model

CST Microwave Studio was employed as the numerical solver. The dipole was excited using a discrete port placed across the gap. Figure 2 shows the peak SAR averaged over 1 g of layered tissue volume and point location of maximum SAR with respect to the surface of the layered tissue for different combinations of skin, fat and muscle tissue thickness.

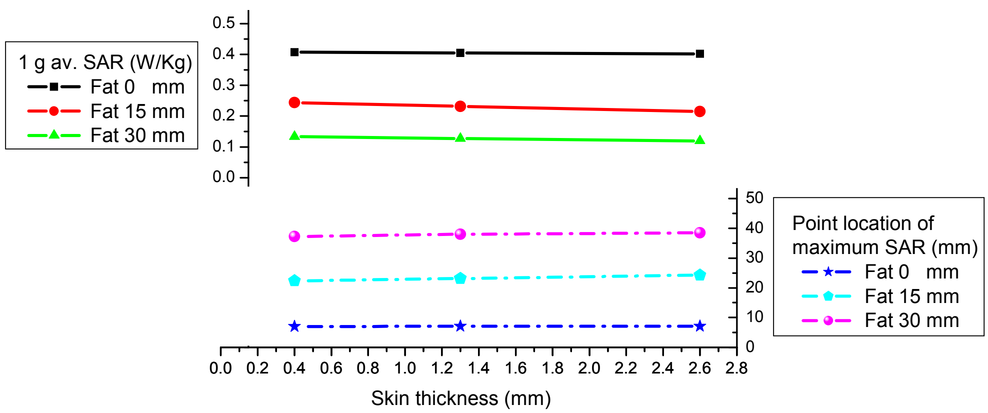

Fig 2. SAR averaged over 1g of layered tissue volume and point location of maximum SAR respect the tissue surface.

The peak SAR decreased as the fat thickness layer increased. The point of maximum SAR was, in all the cases, located in the muscle layer and was deeper when the fat layer thickness increased. Figure 2 shows that the averaged SAR and the point location of maximum SAR are mainly dependent on fat thickness.
Figure 3a shows the SAR depth distribution for the leanest layered tissue model (0.4 mm of skin and 0 mm of fat) and Figure 3b shows the fattest layered tissue model (2.6 mm of skin and 30 mm of fat). Figure 3a is four times the scale of Figure 3b to illustrate the SAR range.

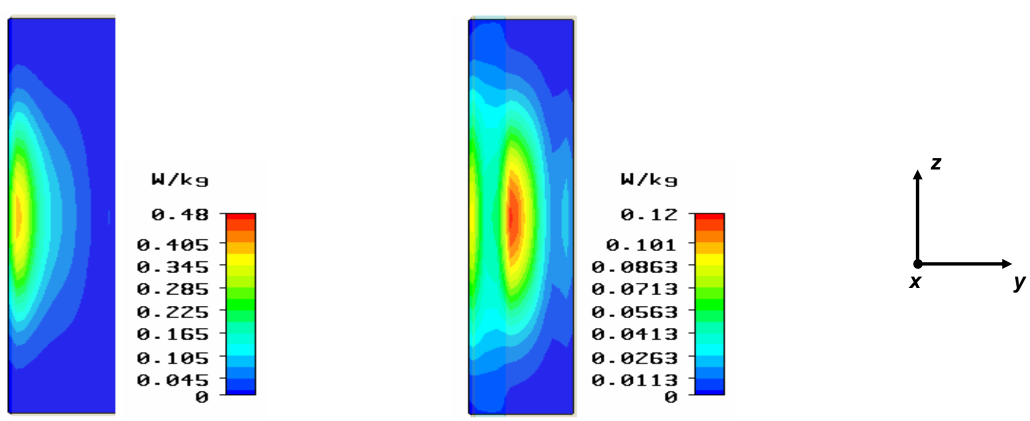

Fig. 3. Point location of maximum SAR and coordinate system for a) 0.4 mm of skin and 0 mm of fat tissue and b) 2.6 mm of skin and 30 mm of fat tissue.

Conclusion

The electromagnetic interaction due to a dipole antenna 50 mm distant from a planar multi-layered human tissue model at 434 MHz was investigated. With a constant skin tissue thickness, the maximum SAR is located at comparable depths behind the fat tissue and is reduced by 70% when the fat thickness increases from 0 to 30 mm. The next step in this research is to investigate the interaction between the antenna and the model with other distances in order to provide a method to develop more efficient and smaller antennas for medical applications.

Acknowledgments

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