

Modeling and Simulation of Radiation-proof Clothing for Pregnant Women based on Finite Element Method^{*}

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Abstract

Relevant research shows that pregnant women have a high sensitivity to electromagnetic radiation. At present, there is a lack of digital evaluation system for the simulation model of the degree of electromagnetic radiation exposure of pregnant women and the effectiveness of electromagnetic radiation shielding clothing for pregnant women. In this paper, the simulation model of pregnant woman and fetus is proposed, and the virtual fitting software is used to model the clothing, and finally the three-dimensional electromagnetic simulation software is used to combine the model and simulate the real situation. In this paper, the effects of electromagnetic radiation on pregnant women and fetuses before and after wearing electromagnetic radiation protective clothing were studied by means of digital evaluation. The results showed that the influence of electromagnetic radiation on pregnant women concentrated in the neck, chest, abdomen, leg; To a certain extent, electromagnetic radiation protective clothing can reduce the impact of radiation on pregnant women and fetuses. In this paper, a digital evaluation method is proposed, which provides a new idea for testing the effectiveness of electromagnetic shielding for pregnant women.

Keywords: Radiation proof clothing; A pregnant woman; Finite element model construction; Shielding effectiveness

1 Introduction

At present, the frequency band used in mobile communication is microwave frequency band, which is closely related to People's Daily life. Microwave is a physical occupational disease hazard factor, its impact on the human body has been more and more attention [1]. In life, electromagnetic radiation has penetrated into every corner, electromagnetic radiation is colorless and silent, so that people tend to neglect their own protection. Research shows that pregnant women this kind of special groups are more vulnerable to electromagnetic radiation damage [2], so some anti-electromagnetic radiation maternity clothes came into being.

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As a kind of functional clothing, how to evaluate the protective effect of radiation-proof maternity clothing has aroused people's thinking. Scholars at home and abroad have also carried out corresponding studies on the effectiveness and influencing factors of electromagnetic shielding of clothing. In terms of physical experiments, considering the harm of electromagnetic radiation to human body, real dressed human bodies are generally not used for experiments. Peng Zhang et al. [3] adopted full-wave darkroom method to test the shielding efficiency of dummy chest and abdomen. Zhang Xiaoxia [4] made the FRP pregnant woman table and experimental sample for the experiment, and analyzed the factors affecting the shielding efficiency of the clothing combined with the structural characteristics of the clothing. Chaochan Chen et al. [5] established a darkroom electromagnetic shielding suit performance test system. In the aspect of finite element simulation experiment, Zhang Lili et al. [6] used Ansoft HFSS to simulate and analyze the influence of body shape changes of pregnant women in different pregnancies on clothing shielding effectiveness. Yao Li [7] used HFSS to simulate the GTEM cell shielding test system. Sun Ruili [8] established a simulation model of clothing pores based on clothing structure. Ma Liang [9] established a simplified model of human body and clothing, and simulated the electromagnetic radiation values at different tissue levels of the human body by using electromagnetic field finite element technology. According to previous studies, the finite element method greatly simplifies the experimental process when studying the shielding efficiency of clothing, and can accurately reflect the distribution of electromagnetic field on the human body, saving economic cost and time cost.

In the evaluation of the shielding effectiveness of pregnant women's clothing, most studies mainly focus on the effects of clothing structure, clothing pores, dummy models and other aspects on the shielding effectiveness, while few studies on biological electromagnetic models and clothing models with similar real situations. The research content of this paper will be based on finite element simulation, modeling of pregnant women and fetuses and modeling and simulation of radiation protective clothing. At present, in the field of clothing performance simulation, biomechanical model and clothing mechanical performance simulation are mostly used. This study created a more complete biological electromagnetic model of pregnant women and fetuses on the basis of previous studies, and combined with virtual fitting software for clothing modeling that is more in line with the reality. The purpose of this paper is to provide a safe and convenient method for testing the effectiveness of clothing shielding, and to provide a new idea for the optimization of clothing products. As for the functional clothing against electromagnetic radiation, it is necessary to ensure the reliability of clothing performance, and multiple physical experiments will increase the production cost of clothing, so using computer simulation method will provide a more convenient new idea for clothing product design.

2 Establishment of simulation model

2.1 Establishment of human body model

The simulation model mainly includes two parts: the pregnant woman model (late pregnancy) and the fetus model (late pregnancy). The two models are constructed by using the method of reverse modeling. The general steps of reverse modeling are as follows: determine the scanning scheme – solid point cloud scanning – conduct point cloud data – establish surface – solid modeling. In this study, the non-contact 3D body scanning equipment used in the pregnant woman model was the

German Human Solution laser 3D body scanner, and the fetal model was the flatbed scanner. At present, the pregnant woman model has been obtained according to previous studies [10]. After the human body model is scanned, point cloud data of 3d human body will be obtained. The software Geomagic will be used to preprocess the obtained point cloud data, edit polygons, and then make precise surface to get the final simulation model.

2.1.1 Fetal model

The figure above shows the polygon processing of the fetal model, while the Fig. 1 shows the cavity filling and relaxation processing of the fetal model. Once the polygons are processed, you need to use Geomagic's Precise surface function to generate the desired mesh of surfaces. The main task of the precision surface stage is to edit contour line and surface piece. Contour line editing refers to contour line detection, extraction and editing, etc., while surface piece editing mainly refers to surface piece editing, surface piece relaxation and surface piece repair, etc. The specific operation flow chart is shown in Fig. 2 below.

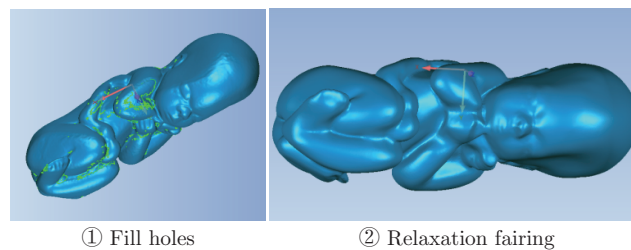


Fig. 1: Model processing

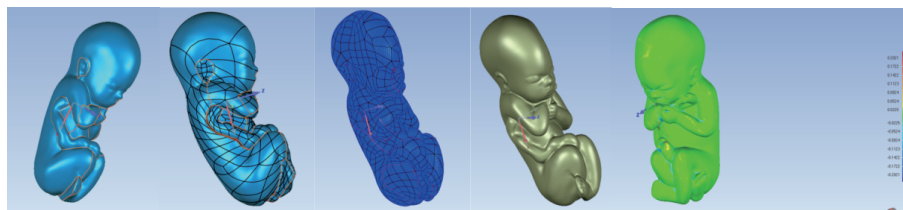


Fig. 2: Model processing

2.1.2 Assembly of human body model

The assembly of the pregnant woman and fetus model refers to the mathematical model of the pregnant woman and fetus established by Jing Che [11] and the Chinese reference human pregnant woman model established by Tang Xiaobin [12] et al., which mainly includes the establishment of the pregnant woman's uterus in the late trimester and the assembly of the fetus and uterus. The uterine model of pregnant women is mainly divided into three stages, namely early, middle and late pregnancy, as shown in the figure. The uterus model in the third trimester is mainly composed of two hemispheres and a cone in the middle. In order to simplify the model and reduce the amount of calculation, uterine wall, placenta and amniotic fluid are not considered here.

As shown in Fig. 3, the software Simcenter is used to establish the geometric model of the pregnant woman's uterus. The process of establishing the geometric model mainly includes selecting the section, sketching, rotating and subtracting, and finally combining the fetal model.

The combination method of the human body model can be relatively simple to combine the human body model, so that the final simulation can obviously express the electromagnetic radiation inside and outside the pregnant woman's body.

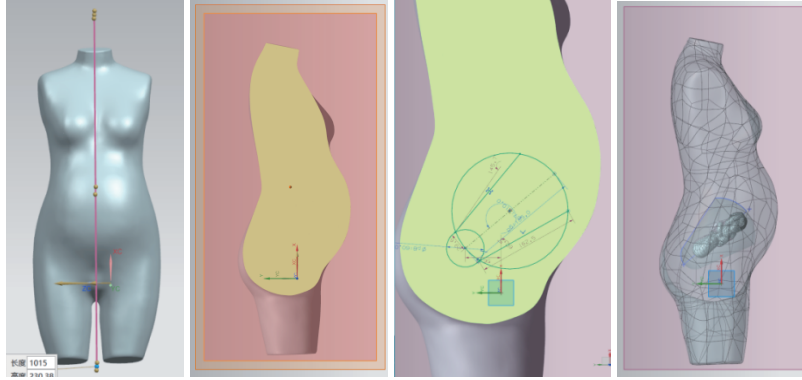


Fig. 3: Pregnant woman model processing process

2.2 Antenna model and environment model

2.2.1 Antenna model

Considering the complexity of antenna model, simple and common antenna structure is selected for simulation. Half wave dipole antenna is a simple basic line antenna, it is also a more classical and simple antenna. The antenna consists of two straight wires of equal diameter and length. The establishment of antenna model is based on the book HFSS Antenna Design [13]. The length of the wire is $1/4$ wavelength, the diameter is much smaller than the working wavelength, and the distance between the middle ends is much smaller than the working wavelength.

The antenna model designed here is a half-wave dipole antenna with a center frequency of 900MHz. The antenna material is an ideal conductor with a total length of 0.48λ and a radius of $\lambda/200$. The antenna is fed by lumped port excitation and the impedance is set to 50ω . According to the formula below, it can be calculated that when the frequency of electromagnetic wave is 900 MHz, the wavelength of electromagnetic wave is about 0.33 m.

The propagation velocity of electromagnetic wave in vacuum: $c = 3 \times 10^8$ m/s; Frequency of electromagnetic wave: $f = 900$ MHz = 9×10^8 Hz; Wave length of electromagnetic wave: $\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{9 \times 10^8 \text{ Hz}} \approx 0.33$ m.

Table 1: The establishment of antenna model

Variable meaning	A variable's value (mm)
Working wavelength	λ
Total antenna length	0.48λ
Port distance	0.24
Single pole length	$(0.48\lambda - 0.24)/2$
Radius of the antenna	$\lambda/200$

2.2.2 Environment model

Before simulation, radiation boundary conditions need to be set to simulate open free space. In the finite element solution, setting the boundary condition at the infinite distance will affect the simulation solution speed. Antenna is a kind of radiation structure, and its radiation boundary is at the infinite distance theoretically. After setting radiation boundary, free space can be effectively simulated. The distance of radiation boundary from human body is no less than $1/4$ wavelength. As shown in the Fig. 4, the cuboid air box needs to cover the antenna and the mannequin. The distance between the mannequin and the antenna is about 1.3 m, so the length of the air box is set as 1.8 m and the width is set as 0.4 m. The radiation boundary of the antenna is the size of the air box. The shape of radiation boundary is shown in the figure, which is a cuboid model.

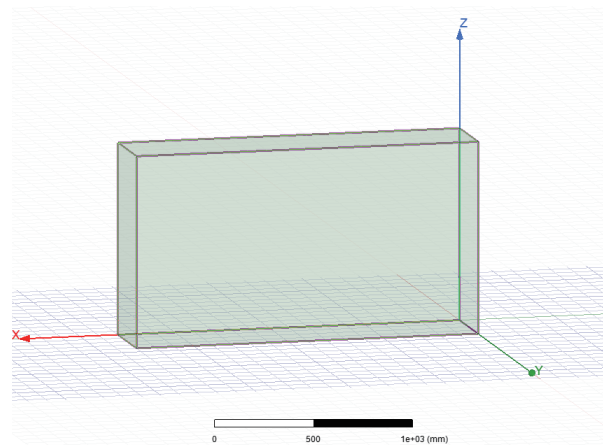


Fig. 4: Air box

2.3 Clothing model

A hybrid modeling approach is adopted for the garment model, which mainly includes forward design (CLO3D software) – constructing a model of a pregnant woman’s electromagnetic radiation resistant garment, and reverse design (Geomagic software) – processing the forward design garment model, and finally assembling it with a human body model in electromagnetic simulation software. The main process of modeling is as follows: firstly, clothing plate making is carried out according to the body type of pregnant women, and then the drawing board is imported into virtual fitting software for fitting, and then the clothing model established in the virtual fitting software is exported to OBJ format. Since the exported garment model cannot be simulated directly in the electromagnetic simulation software, the garment model needs to be processed in Geomagic before simulation.

As shown in Fig. 5(a), the pattern is first made in Clothe3D. The processing process of the garment model in GEOMAGIC is shown in the figure above. Since the imported garment model has many pleated structures, the model needs to be processed and smoothing in and out by removing features (b), simplifying polygons (c), loosening polygons, deleting nails, accurate surface (d) and other steps. The processing sequence can be adjusted according to the situation of the model. Finally, after stretching with SpaceClaim, it is imported into the electromagnetic simulation software for simulation, Fig. 5(e).

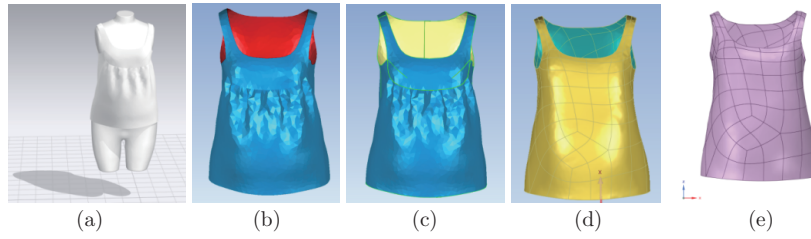


Fig. 5: Clothing model processing process

3 Operation of simulation model

3.1 Assembly of simulation model

HFSS electromagnetic simulation software is a three-dimensional simulation software based on electromagnetic field theory to solve electromagnetic wave problems. It needs to solve Maxwell's equations under certain boundary conditions and excitation conditions. The simulation model established above needs to be assembled and run in the electromagnetic simulation software, as shown in Fig. 6 below. The antenna model, clothing model and human body model need to be assembled together. According to GB/T2017, the human body model is facing the transmitting antenna, and the main lobe of the antenna model is directly facing the abdomen of the pregnant woman model, and the transmitting antenna is at the same height as the test point [14]. Then the corresponding material parameters of human body and clothing are given. Among them, the material parameters of human body are set according to GB/T 33615-2017 Garment Electromagnetic Shielding Effectiveness Test Method.

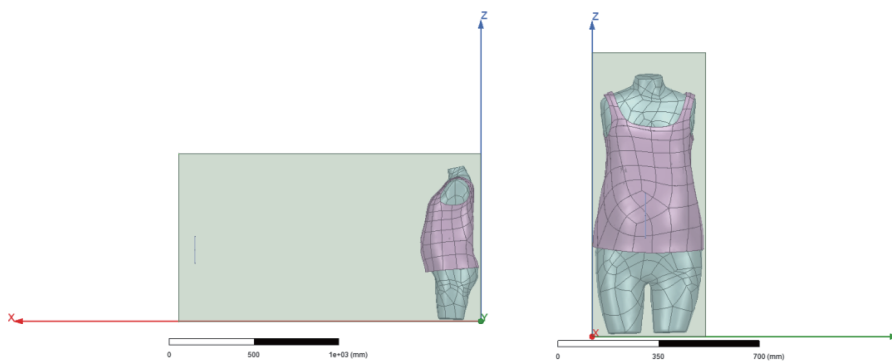


Fig. 6: The simulation model

3.2 Running results and analysis of the simulation model

After assembling the model required by the simulation experiment, two groups of simulation experiment models before and after the human body wearing anti-electromagnetic radiation clothing were respectively run (the difference between the two groups of models only lies in whether there is a clothing model), and two groups of different simulation experiment results were obtained. There are various methods to verify the simulation model. This paper selects the method of literature verification to verify the model constructed. Ma Jian [15] pointed out in the paper that when the antenna is irradiated in the abdomen, the neck, upper chest, lower chest and thighs

of pregnant women are exposed to the most serious radiation. Fig. 7 shows the radiation cloud of human body subjected to electric field intensity before wearing clothing. Figure 8 shows the radiation cloud of electric field intensity of human body after wearing clothing. Figure 9 and 10 show the energy cloud of electromagnetic radiation absorbed by various parts of human body before and after wearing the anti-electromagnetic clothing.

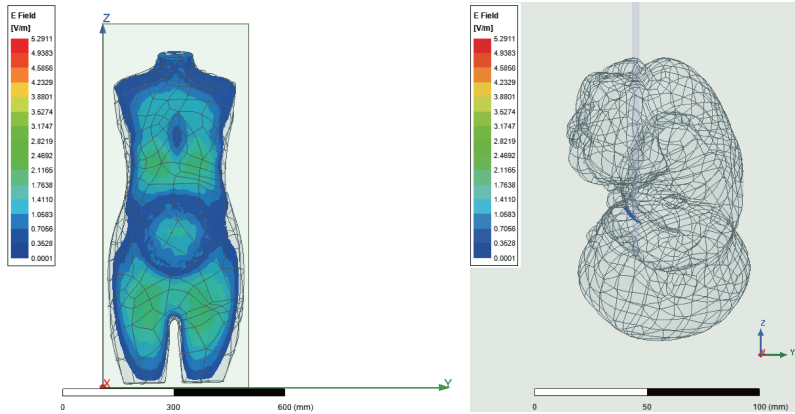


Fig. 7: Unclothed model radiation cloud image

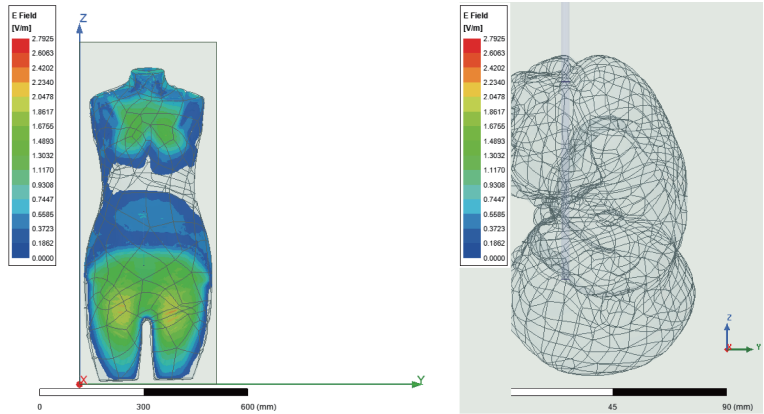


Fig. 8: Model radiation cloud image after dressing

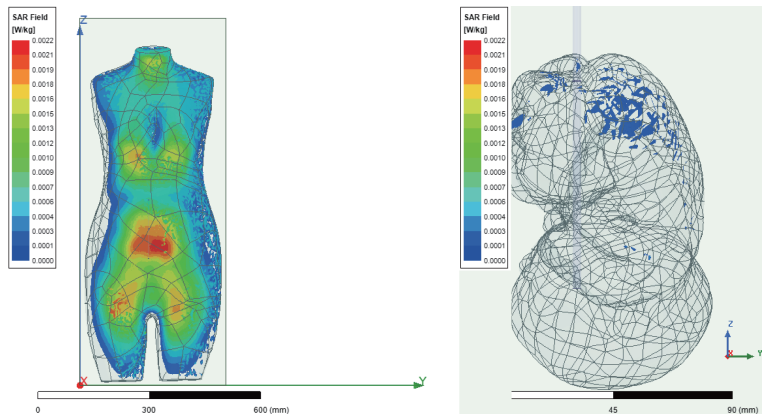


Fig. 9: SAR value for the unclad model

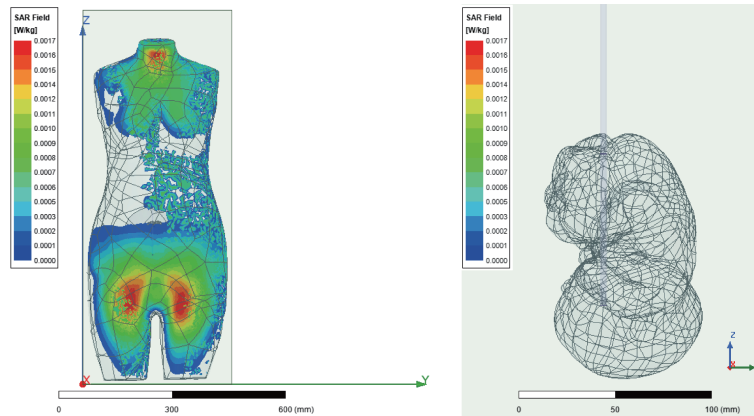


Fig. 10: SAR value of the model after dressing

From the simulation results in the figure above, we can observe that the radiation received by the front side of the human model is significantly greater than that received by the side of the human model, and the electric field radiation received by the pregnant woman and the fetus without wearing electromagnetic radiation clothing is significantly higher than that received by the wearing clothing. In not wearing electromagnetic clothing, pregnant women's chest, abdomen, upper thighs of the three parts of the radiation degree is higher, the fetus will receive a small dose of electric field radiation; After wearing the clothing, we can obviously observe that the abdomen of the pregnant model almost avoided being exposed to electric field radiation, but the parts of the chest and thigh were still significantly affected by radiation, while the fetal model was almost not exposed to electric field radiation. In the SAR cloud image, we can also observe similar results: without wearing electromagnetic radiation protective clothing, the electromagnetic radiation energy absorbed by the neck, chest, abdomen and upper thigh of the pregnant model is the highest, and the electromagnetic radiation energy absorbed by the abdomen of the pregnant model is the highest. The back of the foetus received a smaller dose of electromagnetic radiation. After wearing clothing, the neck and upper thigh of the pregnant model absorbed more electromagnetic radiation energy, while the abdomen absorbed less electromagnetic radiation energy. The fetal model absorbs little electromagnetic radiation energy.

Through the simulation results, we can find that electromagnetic radiation has an impact on the main parts of the female neck, chest, abdomen, upper thigh, and there is no direct evidence that electromagnetic radiation has no impact on the human body.

4 Conclusion

In this paper, by establishing the model of pregnant women and fetuses and conducting simulation experiments in three-dimensional electromagnetic simulation software, we studied the electromagnetic radiation exposure of pregnant women and fetuses when wearing anti-electromagnetic radiation clothing and wearing clothing under 900 MHz electromagnetic radiation. Through the study found that pregnant women in the neck, chest, abdomen, upper thigh by electromagnetic radiation of the greater impact, and the fetus by electromagnetic radiation less. Wearing anti-electromagnetic radiation clothing can effectively reduce the range of electromagnetic radiation, through three-dimensional electromagnetic simulation software, combined with virtual fitting soft-

ware, we can better design the anti-electromagnetic radiation clothing structure, so that it can more effectively protect pregnant women and fetuses.

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