# Dispersive FDTD Modeling of *In-Situ* Electric Fields in Adults and Children Due to Conductor Contact of Charged Human

Akimasa Hirata, Teruyoshi Koyama, and Osamu Fujiwara
Nagoya Institute of Technology
Gokiso-cho, Showa-ku, 466-8555, Japan
ahirata@nitech.ac.jp

**Abstract — A threshold injection current in the child and adult female which elicits biological responses has been reported to be lower than that in the adult male. We considered anatomically-based Japanese adult male and female models and 3-year-old child model, and then analyzed the *in-situ* electric fields due to transient contact current from charged human body. Dispersive finite-difference time-domain method was used, in which biological tissue is assumed to obey a 4-pole Debye model. *In-situ* electric fields of child models were found to be higher than that of the adult models because of its smaller cross-sectional area of the hand and forearm. This morphological difference could be a rationale for the difference of threshold current between adults and children.**

## I. INTRODUCTION

There has been increasing public concern about adverse health effects due to electromagnetic fields. Contact currents would cause indirect effects of EM fields on humans. In the frequency range up to approximately 100 kHz, the flow of electric currents may result in the electro-stimulation of muscles and/or peripheral nerves. The feature of the contact current is that *in-situ* electric fields largely depend on current pathways, which is significantly different in actual scenarios [1].

When a human touches a conducting object with a different electric potential, spark discharges could occur, which produce transient current that flows from/into the human, resulting in an electric shock. A finite-difference time-domain (FDTD) method was implemented to simulate electrostatic discharges (ESDs) in an anatomically-based human body model [2]. In their modeling, however, the standard ESD current for contact discharges being specified in International Electrotechnical Commission (IEC) standard 61000-4-2 was injected from the forefinger, which does not simulate any ESD events from charged human bodies. In addition, the human tissues were simplified as non-dispersive. In these circumstances, time evolution of *in-situ* electric fields in anatomically-based human models is essential to investigate for the condition causing electro-stimulation.

In the present study, using anatomically-based Japanese models of adult and children [3], we utilized a dispersive FDTD method to compute transient contact currents and the resultant *in-situ* electric fields from a charge human.

## II. MODEL AND METHODS

### A. Models

Whole-body voxel models for a Japanese adult male and a Japanese child were developed by Nagaoka et al. [3]. The resolution of these models was 2 mm segmented into 51 anatomical regions. The resolution of these models was kept to 2 mm. The arm of the models are bent manually

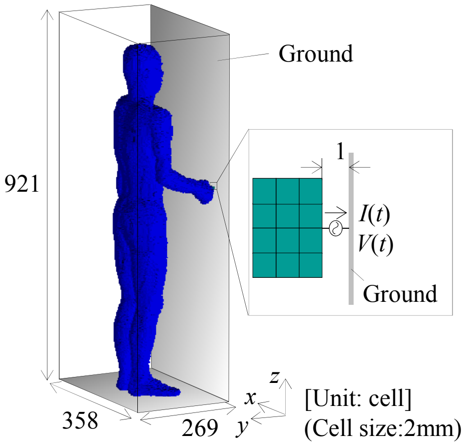

Fig. 1. Computational Condition.

### B. Computational Methods

In order to take into account dispersive characteristics of biological tissues, we assumed that human tissues obey the dispersion properties of a four-pole Debye medium, which can be expressed as

$$\varepsilon_r(\omega) = \varepsilon_\infty + \sum_{p=1}^{4} \frac{\Delta\varepsilon_p}{1+j\omega\tau_p} + \frac{\sigma_0}{j\omega\varepsilon_0} \qquad (1)$$

where $\varepsilon_r(\omega)$ is the complex relative permittivity, $\varepsilon_\infty$ the relative permittivity at infinite frequency, $\sigma_0$ the DC conductivity, $\Delta\varepsilon_p$ the change in the $p$-pole relative permittivity, $\tau_p$ the $p$-pole relaxation time, and $\varepsilon_0$ the free-space permittivity. These parameters were determined by the least squared method in comparison with a 4-Cole-Cole model [4] in the frequency region between 10 kHz and 10 GHz. Even though we chose the lower frequency as 10 kHz, our computation is expected to be reasonable for much lower frequencies. This is because tissue conductivity is almost constant at frequencies below 10 kHz, in addition that the conduction current is dominant compared to the displacement current below 10 kHz. The bandwidth considered herein is much wider than that in previous studies (e.g., [5])

### C. Computational Conditions

Figure 1 shows an FDTD model for analyzing contact currents and *in-situ* electric fields. The side length of the FDTD cell was chosen as 2 mm, which coincides with the human model resolution. The human model was placed above the bottom ground at a distance of $d$ = 10 mm. The contact discharge from a charged human body to a conducting plate was assumed to be considered as an ideal switch (or shorted), which was simulated by applying a stepwise voltage source in one cell gap between the metal piece and the ground (vertical aluminum plate) as shown in figure 1. This excitation method should yield overestimation and scalable results by charge voltages.

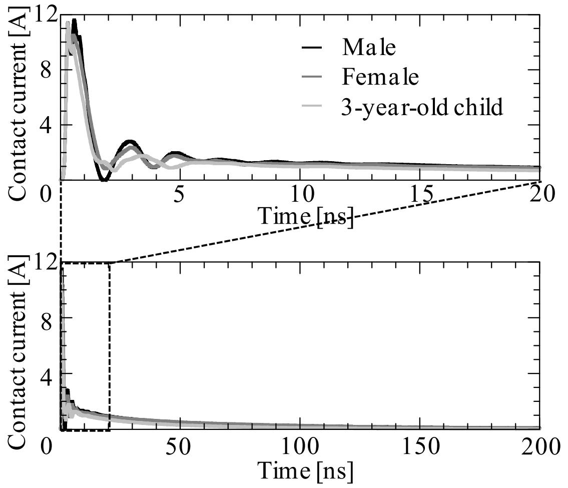

Fig. 2. Time evolution of contact current.

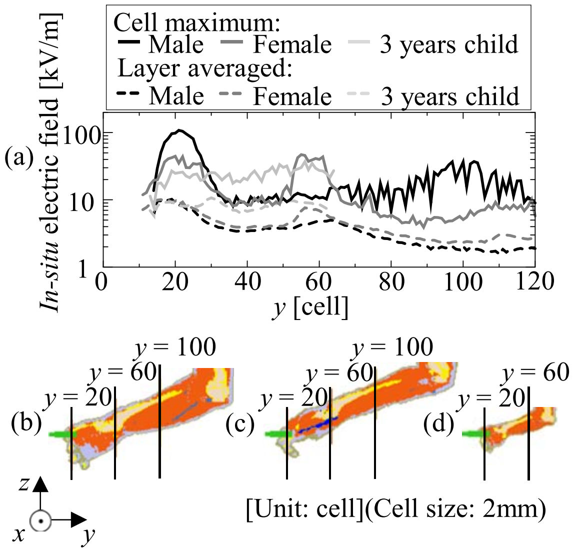

Fig.3. (a) Distribution of maximum *in*-situ electric field in the arm of (b) adult, (c) female, and (d) 3-year-old models.

## III. RESULT

Figure 2 shows computed waveforms of the contact currents through a hand-held metal piece from a human with a charge voltage ($V_C$) of 1 kV. The rise time of the current was the order of one hundred picoseconds, which was comparable to the measured value [6], suggesting the validity of our computational modeling. The contact current consists of a steeply rising current pulse and a slowly falling current. The first part of the current is generated by the discharge from stray capacitance between the metal piece and the ground, and the second current is due to the discharge from the body capacitance. After the first peak, some difference can be observed in the amplitude and oscillation period of contact current. The reason for this difference would be attributed to the morphological differences of the body.

*In-situ* electric fields in the arm of the adult and child models are compared in Fig. 3. From Fig. 3, the cell maximum value of *in-situ* electric field of the adult male appears around the conductor ($y$ = 21) and the forearm ($y$ = 103), while the layer-average value becomes maximal around the wrist ($y$ = 21), in addition to the conductor ($y$ = 19). The cell maximum and layer-averaged values are influenced by the anatomical composition and the cross-sectional area, respectively. Similar tendency was observed for different models.

Except around the conductor, *in-situ* electric field of the 3-year-old child model is larger than those of the adult models. This tendency coincides with the report that a threshold injection current in the child which elicits biological responses has been reported to be lower than that in the adult male.

## IV. SUMMARY

We have developed a computational model based for conductor contact of charged human based on dispersive FDTD method. It was also confirmed that *in-situ* electric field becomes large around the metal piece and small sectional area on the current path. *In-situ* electric fields of 3-year-old child model were found to be larger than that of the adult models, because cross-sectional area of the hand and forearm of child model.

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