# Whole-Body Average SARs in Korean Male Models

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## Abstract

Compliance of the reference level (electric field strength) to the basic restriction (whole-body average SAR) was examined when Korean male models at the ages of 1, 3, 5, 7 and 20 years are exposed to a plane wave in the frequency range of 10 MHz - 3 GHz. We considered the standing postures with arms up as well as arms down. The WBA SAR values in the human models isolated and grounded were calculated using the finite-difference time-domain (FDTD) method. The electric field values required to produce 0.08 W/kg were calculated in all models and compared with the reference levels of the ICNIRP guidelines and the action levels of the IEEE Std C95.1-2005. The results show that the current exposure limits are not conservative in frequency regions of lower than 200 MHz and higher than 1 GHz. The basic restrictions regarding the WBA SAR were chosen to provide a safety factor (the ratio of the WBA SAR to 4 W/kg, the threshold for potentially adverse effects) of 50 for public exposure. In these regions, the lowest safety factor for the ICNIRP reference levels was calculated as between 30 and 35.

## 1. Introduction

The reference levels and action levels (the maximum permissible exposure for the general public), produced by the ICNIRP [1] and IEEE [2] respectively, are derived from their basic restrictions on SAR. Researches regarding external electric field levels required to produce the WBA SAR basic restrictions, using more realistic human voxel models, have been carried out in the early 2000s [3], [4]. These research results led to change action levels above 300 MHz for public exposure in IEEE Std C95.1-1999 [5]. Thereafter, child models and various postures have been considered to investigate the compliance of the reference levels to the WBA SAR limit 0.08 W/kg in recent years [6-14].

Meanwhile the Electronics and Telecommunications Research Institute (ETRI) developed a child voxel model in the standing posture with arms down to the side using magnetic resonance images of a child volunteer at the age of 7 [15]. Then it has been altered to a sitting and a standing postures with arms up and WBA SAR calculations were carried out [13]. It was found that the WBA SAR could be increased by up to 25% if the model was changed from the arms down to the arms up in a standing posture. Since this result was about only the 7-year-old child model, in this paper we investigated the effects of posture change on the WBA SAR in Korean males at various ages, considering the conditions grounded as well as isolated in free space.

## 2. Human Models and Calculation Methods

The 7-year-old model in the standing postures with arms down and up in Fig. 1 were non-linearly deformed to produce male models at the ages of 1, 3, 5, and 20 years. The external body dimensions at various ages used for the scaling process were provided by the Korean Anthropomorphic Survey [16]. The total sixteen body dimensions such as circumference, depth, width and height were used and they correspond to the 50th percentile values of Korean males at each age. The body weight of the resultant model was checked up. The percentage difference from the 50th percentile body dimension showed an agreement within 5 %.

The FDTD method was used to calculate WBA SAR. In all calculations, the human voxel model was exposed to a plane wave with a vertically polarized electric field. The field was incident to the front of the model. Dielectric properties of each tissue type in the body were assigned according to a 4-Cole-Cole dispersion model in the 10 MHz - 3 GHz range [17].

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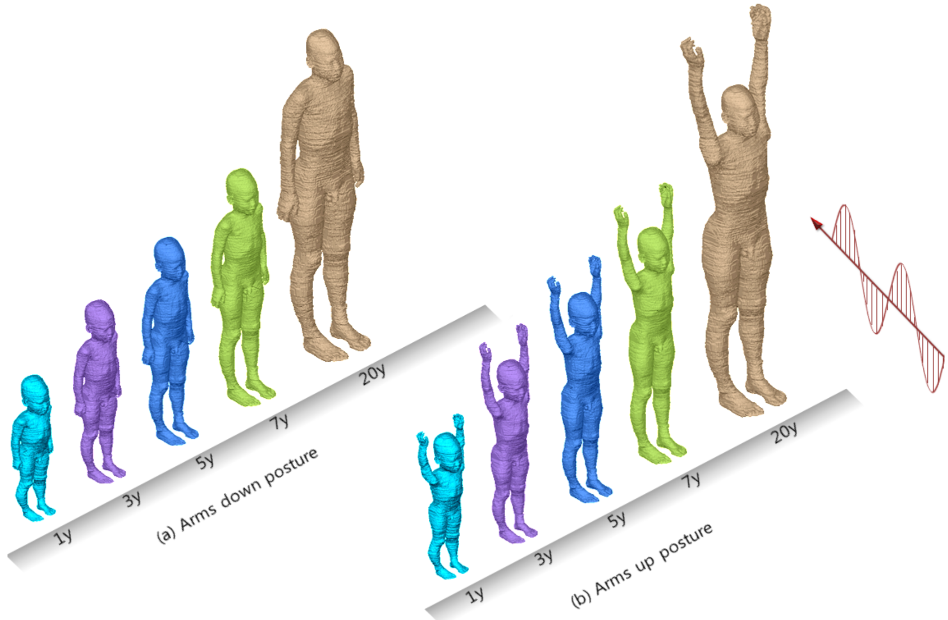



Fig. 1. Human models.

## 3. Results and Discussion

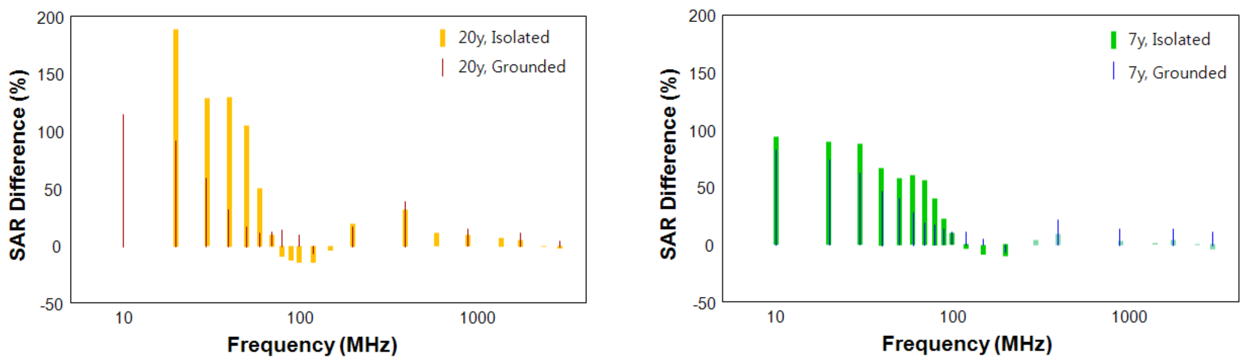
WBA SAR values of all the human models shown in Fig. 1 were calculated under the isolated condition. The grounded condition was applied to only the 1-, 7-, and 20-year-old models. The change of the postures from arms down to arms up increased the WBA SAR at most of frequencies of interest. Fig. 2 represents the SAR difference in percentage for the posture change. SAR increase due to raising arms was more dominant at low frequencies and in the older models. As shown in Fig. 2, the isolated condition provided a larger increase in the SAR rather than the grounded condition; the WBA SAR in the adult increased by more than 100% when the frequency is less than 50 MHz.

The stature, posture and grounding change the resonance frequency of the human body. The whole-body resonance occurred when the height of the body reaches 0.40λ - 0.42λ and 0.24λ - 0.27λ under the isolated and grounded conditions, respectively. The height is the entire length of the human model in the direction of the electric field polarization.

Fig. 3 (a) and (b) compares the reference levels (ICNIRP) and action levels (MPE for the general public) (IEEE C95.1) for public exposure with the lowest electric field levels of the values for all the models, required to produce whole body averaged (WBA) SAR basic restriction, 0.08 W/kg. In each case of Fig. 3, the 20- and 1-year-old models generally contribute to the lowest levels in low and high frequency ranges, respectively. The graphs show that the current reference levels and action levels are not conservative in the frequency ranges of whole-body resonances and gigahertz.

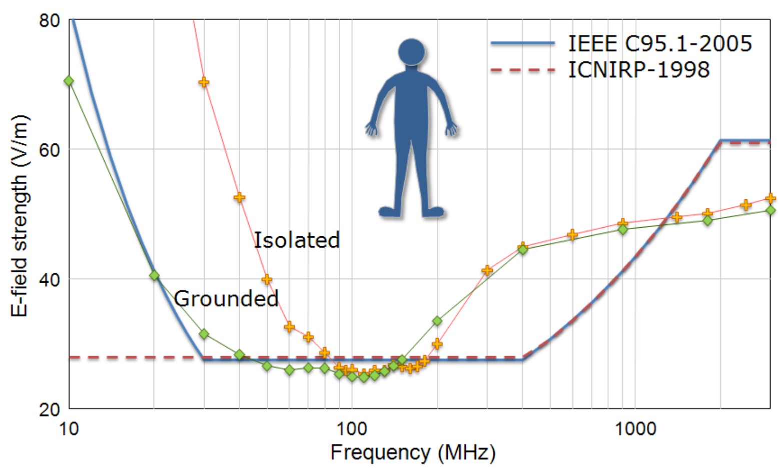
## 4. Conclusion

Behavioural studies involving a variety of exposure conditions have indicated that a WBA SAR value of above 4 W/kg can cause heat related disorders in several animal species including non-human primates [1-2]. The current basic restrictions on the WBA SAR of ICNIRP guidelines and IEEE standard were chosen to provide a safety factor of 10 and 50, the ratio to 4 W/kg -the threshold for adverse effects for occupational and public exposures respectively. The results in this paper show that in wide regions of the considered frequencies the ICNIRP reference levels and IEEE action levels provide a safety factor less than 50 for public exposure.

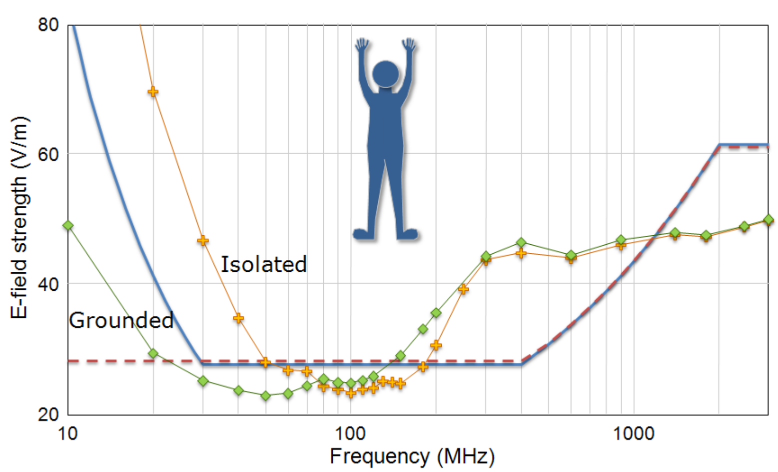



(a) 20-year-old model (b) 7-year-old model

Fig. 2. WBA SAR difference between arms down and up postures (Difference (%) = $(SAR_{arms\ up} - SAR_{arms\ down})/SAR_{arms\ down} \times 100$).




(a) Arms down posture




(b) Arms up posture

Fig. 3. Reference levels and the lowest electric field strengths required to produce basic restrictions, 0.08 W/kg.

## 5. Acknowledgement

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