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# The Age-Dependence of Microwave Dielectric Parameters of Biological Tissues

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Additional information is available at the end of the chapter

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## 1. Introduction

Today's children are being exposed to electromagnetic fields even before they come to this world, while they are growing up in an environment polluted, amongst others, by the dense microwave electromagnetic flux.

Daily exposure, both indoor and outdoor, of younger generations to microwave electromagnetic fields is being followed with the raised concerns regarding possible biological and health effects induced as a result of exposure. Therefore there are many published scientific papers, ongoing research projects and awareness raising campaigns aiming to inform general public and other stakeholders about safety of microwave exposure.

In order to ensure the public safety, based on research evidence, the relevant authorities have developed and announced guidelines and limits for exposure to electromagnetic fields.

Even though there are recommendations and exposure standards and limits given at international level as ICNIRP [1] and IEEE [2], few countries have set even more rigorous country specific exposure limits in comparison with international ones, in terms of setting precautionary measures.

International safety standards and guidelines on exposure limits to electromagnetic fields have been developed based on research evidence for adults, and even though each of them include a specific safety margin it should be confirmed they remain valid for children as well.

Children have longer life time exposure to microwaves in comparison with adults since they are exposed to microwave electromagnetic fields at earlier age in comparison with adults, so the cumulative exposure effect is not to be neglected.

At ICNIRP standards [1] two classes of guidance are presented: 1) Basic restrictions: Restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects. Depending upon the frequency of the field, the physical quantities used to specify these restrictions are current density (J), specific energy absorption rate (SAR), and power density (S). Only power density in air, outside the body, can be readily measured in exposed individuals.; 2) Reference levels: These levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Some reference levels are derived from relevant basic restrictions using measurement and/or computational techniques, address perception and adverse indirect effects of exposure to electromagnetic fields. The derived quantities are electric field strength (E), magnetic field strength (H), magnetic flux density (B), power density (S), and currents flowing through the limbs.

At microwave frequencies the basic restrictions are given in terms of SAR- parameter used to assess absorption of electromagnetic energy by biological tissue.

The SAR, time rate of RF energy absorbed per unit mass of body biological tissue, is given as:

$$SAR = \frac{(\sigma + j\omega\epsilon_0\epsilon_r'')E_i^2}{\rho} \quad (W / kg) \quad (1)$$

Where

$\sigma$  - Conductivity of biological tissue,

$\omega$  - Angular frequency,

$\epsilon_r''$  - Imaginary part of complex permittivity,

$\epsilon_0$  - Permittivity of free space,

$\rho$  -tissue density,

$E_i$  - induced value of electrical field as a result of exposure to external field.

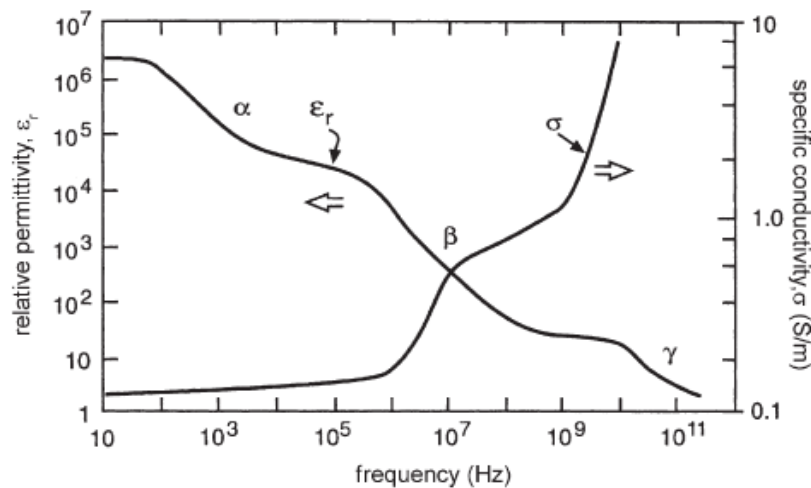
As noticed from relation (1) the SAR depends directly from: induced intensity of electrical field, density of biological tissue and electromagnetic properties of biological tissues at given point. Therefore, a first step in any analysis related with SAR determination is the derivation of electromagnetic properties of biological tissues.

Looking in the other aspect the electromagnetic parameters of human biological tissues are considered very important in the wide range of biomedical applications as reported on [3] such as functional electrical stimulation, diagnosis and treatment of various physiological conditions with weak electric currents, radio-frequency hyperthermia, electrocardiography etc. On a more fundamental level, knowledge of these electrical properties can lead to an understanding of the underlying basic biological processes, for example: one of the first demonstrations of the existence of the cell membrane was based on dielectric studies on cell suspensions.

As for all mediums, the constitutive electromagnetic parameters of biological tissues are the electric permittivity  $\epsilon$ , the magnetic permeability  $\mu$  and the electric conductivity  $\sigma$ . These parameters describe the interaction of external electromagnetic field with medium and determine the pathways of current flow through the human body.

The conductivity of a medium may be considered as a measure of the ability of its charge to be transported throughout its volume by an applied electric field. Similarly, permittivity is a measure of the ability of its dipoles to rotate or its charge to be stored by an applied external field [3].

For almost all mediums the electromagnetic parameters vary with the frequency of the applied signal. Such a variation is called dispersion. Biological tissues exhibit several different dispersions over a wide range of frequencies, as shown in Figure 1, and described in detail in [3]. Dispersion is characterized with the relaxation time or equivalently with relaxation frequency and can be described in terms of the orientation of dipoles and the motion of the charge carriers.



**Figure 1.** Frequency dependence of the dielectric parameters of biological tissues [3]

Biological tissues may be considered as materials with  $\mu = \mu_0$  thus it is of interest derivation of two others parameters: permittivity and conductivity known as dielectric parameters of tissues.

Dielectric parameters of tissues are functions of frequency, but they also depend on temperature and tissue organic composition.

A few studies have presented the variation of permittivity and conductivity as a function of tissue age, triggering scientific community to explore about possible difference of microwave energy absorption between ages and finding more sensitive age- groups to electromagnetic fields exposure.

The age –dependence of dielectric properties of biological tissues mostly relies on the fact that permittivity and conductivity may be expressed as a function of tissue water content (TBW- Total Body Water Content) that is function of age, respectively decreases with age.

The TBW also differs at people of the same age while it is a function of gender as well.

The newborns have higher water content in comparison with fat while biggest part of their mass is composed by visceral organs. Beside water content also development of different organs with age is to be considered.

Therefore there are arguments to elaborate the age-dependence of dielectric properties of biological tissue, and assign different values for different age-groups, especially pointing out the difference between the children, adults and elderly people dielectric characteristics.

*Up to date, based on our knowledge, there is no database with permittivity and conductivity of children biological tissues.*

As a consequence, in many electromagnetic dosimetry research studies the dielectric properties of biological tissues for adults are used due to the lack of information related to children.

The age-dependence of dielectrical parameters of human biological tissues is still debatable at scientific forums and studies are mainly focused on two points:

- Finding a relation that will confirm possible age-dependence of dielectric properties of human biological tissues, respectively answering the question:  
Are the permittivity and the conductivity of human biological tissues a function of age?  
and
- What impact will have the age-dependent dielectric properties on induced SAR values as a result of exposure to incident electromagnetic fields, respectively in dosimetric point of view what will be the difference of microwave energy absorption by different age biological tissue for the same exposure conditions?

For determination of children biological tissues dielectric parameters, and comparison of them with adult dielectric parameters afterward, based on ongoing research, there are two major possibilities:

- *In vivo* measurement of dielectric characteristics of animal biological tissues at different animal age aiming to confirm the age dependence of dielectric properties of animal tissues, where the main raised issue is the extrapolation of obtained results from animal to human biological tissues, respectively finding a correlation of dielectric characteristics of animal and human at different ages.  
Up to date, based on our knowledge, there is no systematic scientific confirmed extrapolation methodology.
- Derivation of empiric formulas for estimating dielectric parameters of human biological tissues as a function of age.
- Possibility for derivation of permittivity and conductivity for each age via mathematical expressions.

In the chapter, the above mentioned methods will be considered, and the main studies on the field will be discussed, by outlining also their advantages and disadvantages from our point of view.

It has to be mentioned that for few external biological tissues, as for the skin as an example, there is a possibility of *in vivo* measurement for determination of dielectric properties. In a report derived by a research project [4] the study with volunteers has been conducted presenting the results for permittivity and conductivity as obtained with *in vivo* measurements including a detailed analysis of possible measurement uncertainties.

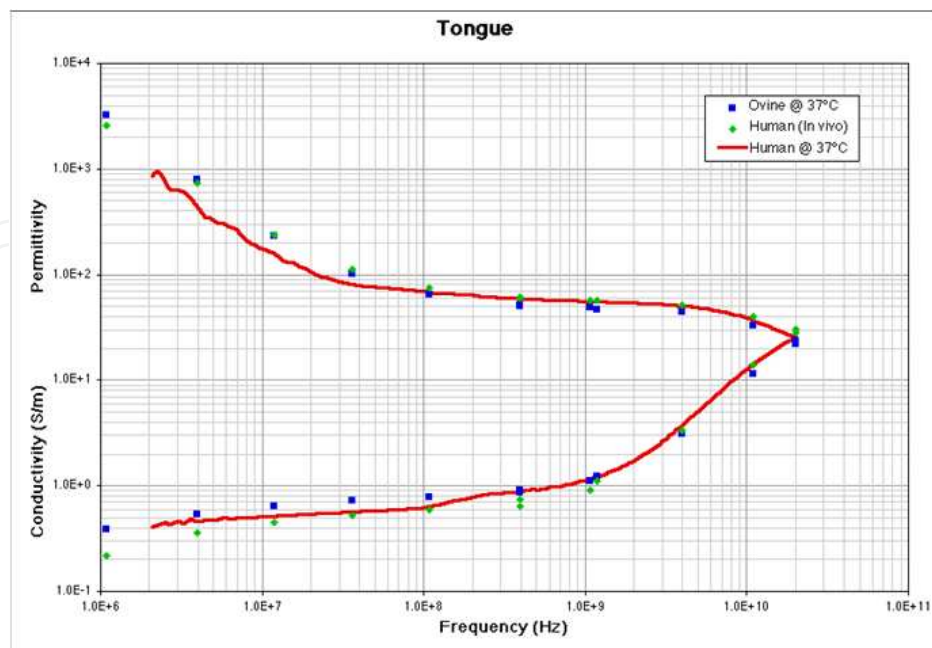
## 2. Dielectric parameters of human biological tissues derived from their correlation with animal biological tissues

For ethical reasons and due to the complexity of *in vivo* research with human biological tissues, especially for children, few researchers have conducted experiments with animal biological tissues tending to confirm the age-dependence of dielectric parameters of biological tissues.

One of the most systematic and cited studies dealing with dielectric properties of biological tissues remains report [5] based on which the database and software applet is developed presenting the values of permittivity, conductivity and the other dielectric characteristics, for main biological tissues at microwave frequencies.

The presented results of permittivity and conductivity of human biological tissues have been obtained by experimental techniques on three types of materials: excised animal tissues, human autopsy materials and *in vivo* human skin and tongue, whose details are given in [5].

The comparison between dielectric characteristics of human and animal biological tissues and between animal species is given on Figures 2, 3 and 4.



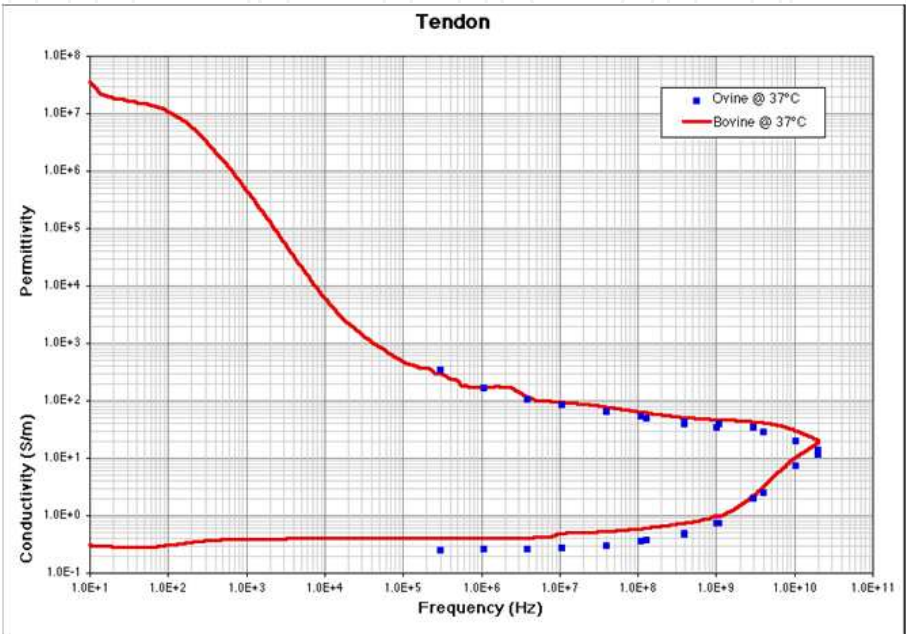
**Figure 2.** Comparison between the dielectric properties of tongue muscle from animal and human samples [5]



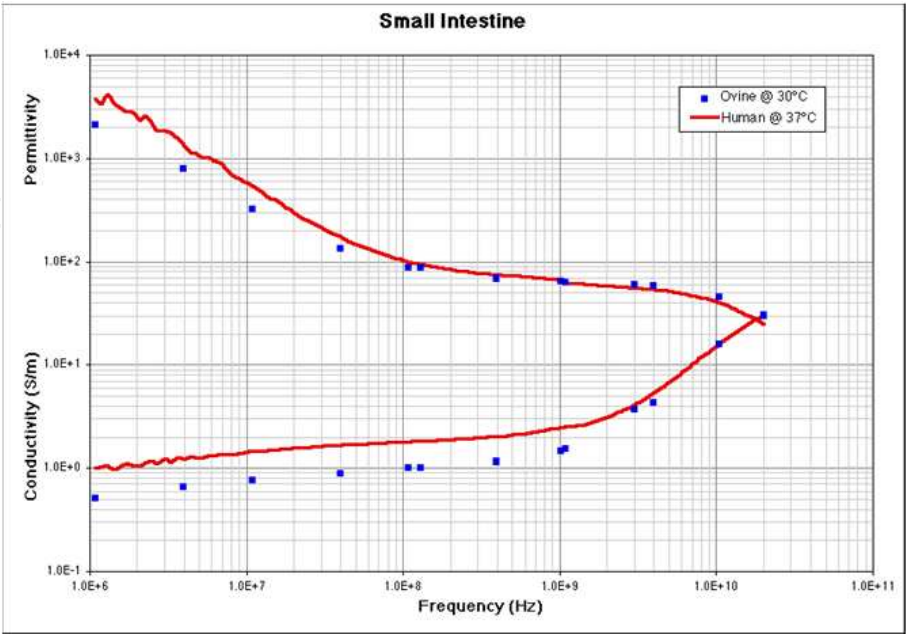
The difference between dielectric parameters of animal and human is not systematic, thus it has to be noted that the difference between dielectric parameters of the same specie may sometimes exceed the difference between the different species.

These differences make the method of extrapolation of dielectric parameters from one specie to the other not sustainable at desired extent.

Nevertheless, from the above figures, the similarity of dielectric parameters variation trend between the animals and human biological tissues can be observed.



**Figure 3.** Comparison between the dielectric properties of tendon from two animal species [5]



**Figure 4.** Comparison between the dielectric properties of small intestine tissue from animal and human samples [5]

Even the study gives detailed results and deep description of research methodologies, providing broad based consensus results on the subject, the age-dependency of dielectric characteristics of biological tissues is not included in software application and the user can not obtain the values of permittivity and conductivity as a function of age.

Few studies have reported variation of dielectric parameters with age mostly for animal biological tissues.

*Thurai et al.* 1984[6] and 1985[7] reported a change on values of dielectric parameters as a function of age for brain of animal tissue.

*Peyman et al.* [8,9] presented the values of experimental measurements of dielectric parameters of rats aged 10-70 days, thus confirming the age-dependence of permittivity and conductivity of the animal biological tissues. In the study, the dielectric properties of ten rat tissues at six different ages were measured at 37 degrees celcius in the frequency range between 130 MHz and 10 GHz, using an open-ended coaxial probe and a computer controlled network analyser. The results showed a general decrease of the dielectric properties with age, with a trend being more apparent for skull, skin and brain tissues and less noticeable for abdominal tissues. The variation in the dielectric properties with age reported in the study is due to the changes in the water content and the organic composition of tissues. The results presented in study have given some insight to research community for possible differences and comparative assessment of exposure between children and adults.

In the review article [10], experimental results are presented on the dielectric properties of tissue samples of 10, 30, and 70 days-old Wistar strain rats in the frequency range 300 KHz–300 MHz. The study concluded that at frequencies higher than 100 MHz, where the  $\gamma$  dispersion is dominant, the permittivity and the conductivity increase monotonically with decreasing age. At lower frequencies, the site of the  $\beta$  dispersion, a change in the frequency dependence of the dielectric parameters is observed and is mostly evident in the spectra for brain and skin. According to this research, it is attributed to changes in the tissue structure.

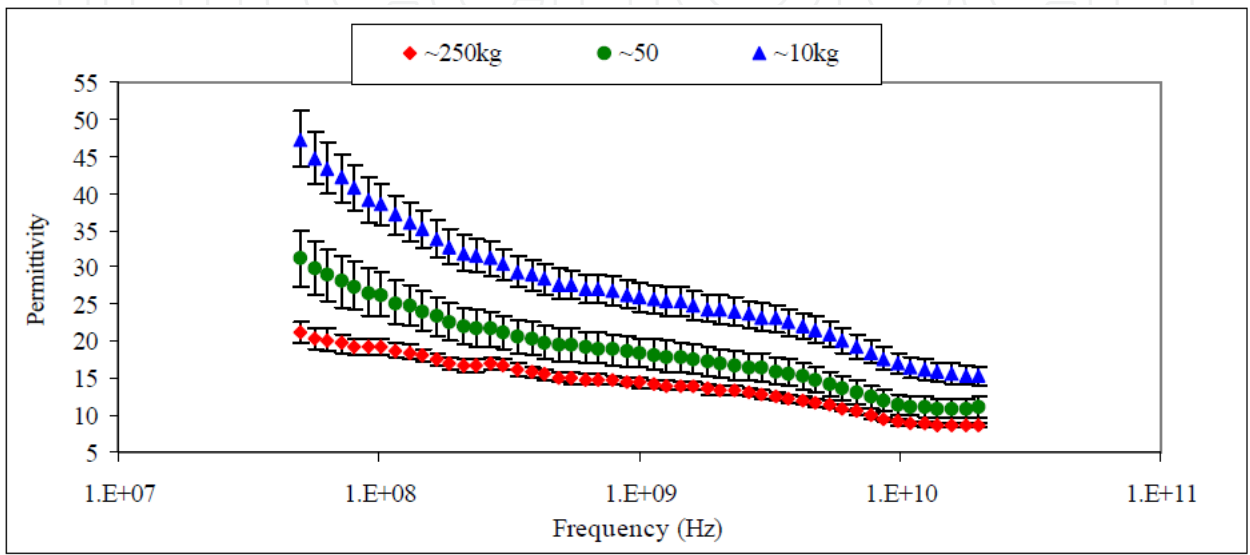
In the same study [10] age-related dielectric data were incorporated in a numerical plane wave exposure dosimetry applied on anatomically heterogeneous rat models with body sizes corresponding to the ages of 10, 30, and 70 days at a number of spot frequencies from 27 to 2000 MHz. The obtained results showed that the variation in the dielectric properties affect the whole body SAR by less than 5% with the most conservative value (highest SAR) obtained when 70 day properties were used.

*Schmid and Uberbacher* [11] have presented the results of experimental measurements confirming that conductivity and permittivity of younger animal tissues were for 15-22 %, respectively 12-15 % , higher than the ones of older animal tissues.

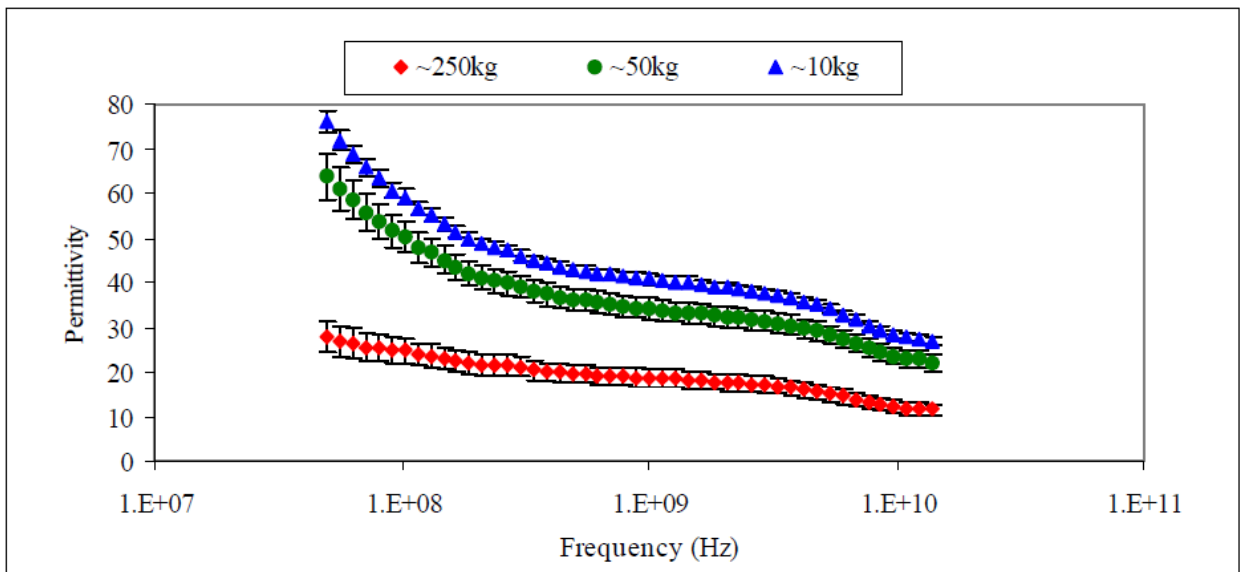
*Peyman et. al.* [12, 13] also conducted measurements of dielectric parameters of pig biological tissues at different ages, re-confirming the age- dependence of dielectric characteristics of animal tissues, and in the same study the correlation between the animal dielectric parameters and human dielectric parameters is given.



The dielectric properties of pig cerebrospinal tissues were measured *in vivo* and *in vitro*, in the frequency range of 50 MHz–20 GHz. The total combined measurement uncertainty was calculated at each frequency point and is reported over representative frequency regions. Comparisons were made for each tissue between the two sets of data and with the literature of the past decade. The *in vitro* study was extended to include tissue from pigs weighing approximately 10, 50 and 250 kg to confirm the issue of the variation of dielectric properties with age.



**Figure 5.** The measured permittivity of the long bone for different age pigs [4]

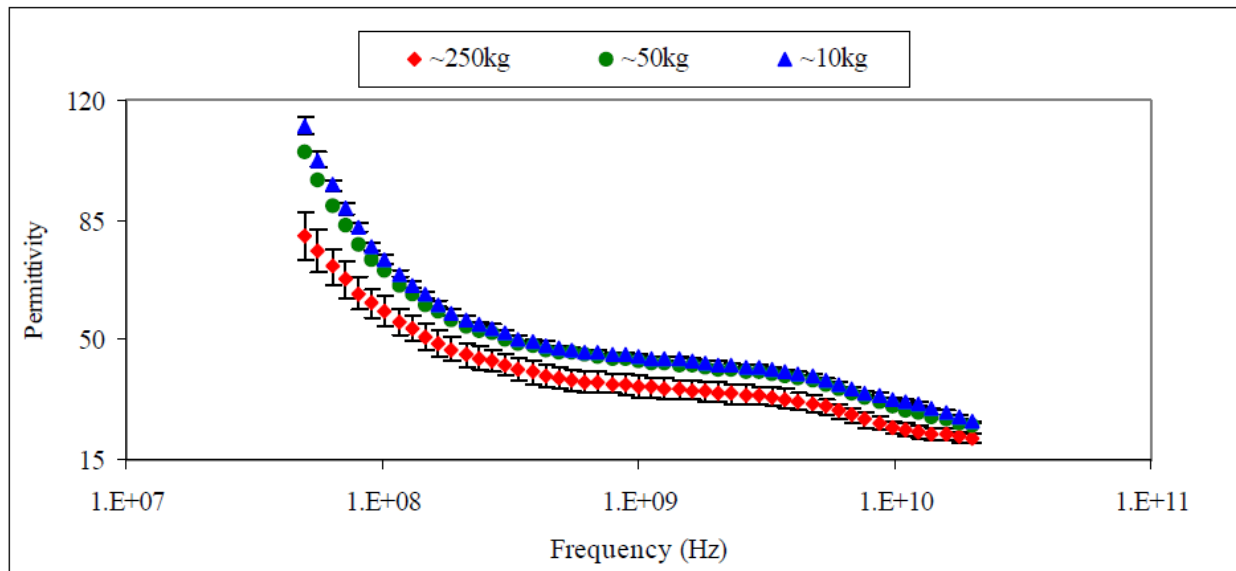


**Figure 6.** The measured permittivity of the skull for different age pigs [4]

As reported on [4] the age related effects were more noted for some tissues types. Results of porcine study showed that at tissues: white matter, dura, fat, skin, skull and spinal cord the

age related effects were noticed, while at tissues as: tongue, cornea and grey matter no age related effects were noticed.

For some tissues at microwave frequencies there was no significant change between results obtained from *in vitro* and *in vivo* measurements.



**Figure 7.** The measured permittivity of the skin for different age pigs [4]

Recalling the study of Peyman et al. [13], based on discussions with numbers of vets, the studies on pig and human growth curves with markers along curves (e.g., sexual maturity etc.), a partial extrapolation of results to humans is reported.

The study concluded that it was more straightforward to correlate the end points, i.e., the piglets to be equivalent to very small children and mature pigs equivalent to adults, whereas the ages in between are more difficult to correlate.

The study reports : 10 kg pigs, which are less than 30 days old, are very young animals and far from puberty age; - it may be assumed that dielectric properties of these piglets correspond to those of human children of age between 1-4 years. The 50 kg pigs , which are about 100 days old , are not still fully matured in terms of sexual activity, and therefore are assumed to be equivalent to 11-13 years old human. Finally, at 250 kg, pigs are fully matured animals and are therefore considered equivalent to human adults.

The results obtained with extrapolation were then used to calculate the SAR values in children of age 3 and 7 years when they are exposed to microwave induced by walkie-talkie devices.

Even though a first steps were made to find a correlation between dielectric parameters of animal and human at different age, still there is no systematic scientific-based general correlation formula or extrapolation methodology that would propose the extrapolation of obtained results of animal dielectric parameters to humans.

### 3. Age-dependent dielectric parameters of human biological tissues derived with analytical formula

The complex permittivity of any tissue, including here the biological tissues, the parameter that contains both: tissues relative permittivity and conductivity, is given by the formula:

$$\underline{\varepsilon}_r = \varepsilon_r' - j\varepsilon_r'' = \varepsilon_r' - j\frac{\sigma}{\omega\varepsilon_0} \quad (2)$$

where:

$$j = \sqrt{-1}$$

- Relative permittivity.

If on relation is added

$\tau$  - the relaxation time of the biological tissue given by the following expression:

$$\tau = \frac{\varepsilon_0}{\sigma} \varepsilon_r \quad (3)$$

By substituting the relaxation constant into the complex permittivity formula (2), the following expression is obtained:

$$\underline{\varepsilon}_r = \varepsilon_r \left( 1 - j\frac{1}{\omega\tau} \right) \quad (4)$$

The plot of the relation between the imaginary and the real part of permittivity at frequency 900 MHz, for few aging rats biological tissues as: the brain, the muscle, the salivary gland, the skin and the skull, based on results presented on [8], confirms that ratio between the imaginary and real part of permittivity is almost constant for different biological tissues as described on [14].

Therefore, it may be concluded that the relaxation constant is almost independent from age and its value can be taken statistically as a mean derived from different ages.

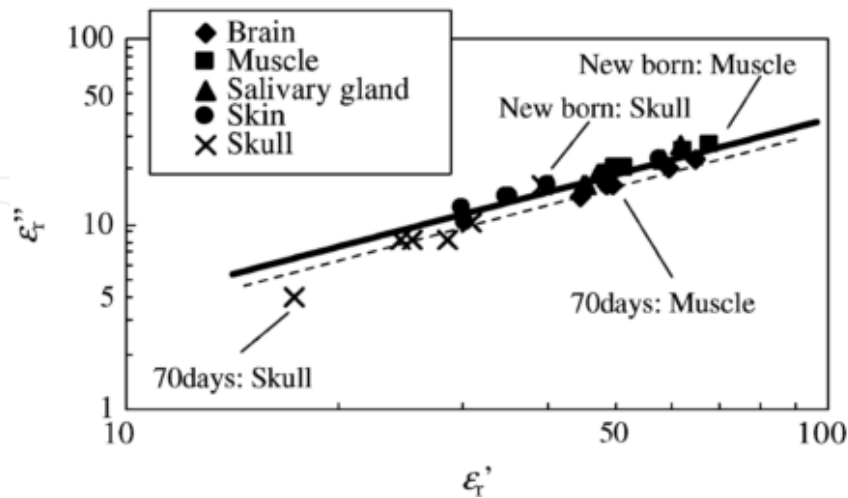
Under the above mentioned assumption, either relative permittivity or conductivity of biological tissue has to be known and the other can be calculated using relation (3).

Referring to mathematical expression (4) the only parameter that may change with age is tissue relative permittivity  $\varepsilon_r$ .

The dielectric parameters of tissue depend on tissue composition.

It is known that human biological tissues are dominantly constituted by water content, therefore if water content changes with age it is to be expected that dielectric parameters change with age as a result of TBW change, and this has to be put in a formula expressing

the function of relative permittivity from age of tissue, respectively TBW, approach proposed by Wang et al. [14] on 2006.



**Figure 8.** Ratio between real and imaginary part of permittivity of biological tissues [14]

### 3.1. Empirical derivation of dielectric parameters of human tissues as a function of age

The relative permittivity based on Leichtencker's logarithmic mixture law [15] for medium consisted from N composites may be expressed as:

$$\varepsilon = \prod_{n=1}^N \varepsilon_n^{\alpha_n} \quad (5)$$

$\varepsilon_n$  - relative permittivity of n composite

$\alpha_n$  - hydration rate of n composite

with sum of all  $\alpha$  equal to one.

For medium consisted from two composites the relative permittivity is given as:

$$\varepsilon = \varepsilon_1^{\alpha} * \varepsilon_2^{1-\alpha} \quad (6)$$

As noted on [15] Leichtencker mixture formula is symmetric with respect to its constituents thus:

$$\frac{\varepsilon}{\varepsilon_2} = \left(\frac{\varepsilon_1}{\varepsilon_2}\right)^{1-\alpha} \text{ can be written as } \frac{\varepsilon}{\varepsilon_1} = \left(\frac{\varepsilon_2}{\varepsilon_1}\right)^{\alpha} \quad (7)$$

Even though formula (6) served as a starting point to Wang et al. [14], 2006, it has been regarded for a long time as semi-empirical formula without theoretical justification. Recently, a 2010 study [16] has confirmed that formula (6) can be derived by applying

Maxwell's equations and the principle of charge conservation to a mixture for which the spatial distribution of shapes and orientations of the components is randomly distributed.

According to Wang [14] the biological tissues may be considered as given by two composites: water and organ specific material, therefore the relative permittivity of human biological tissues may be given as:

$$\epsilon_r = \epsilon_{rw}^{\alpha} \cdot \epsilon_{rt}^{1-\alpha} \quad (8)$$

$\epsilon_{rw}$  - relative permittivity of water,  
 $\epsilon_{rt}$  - organ specific relative permittivity  
 $\alpha$  - tissue hydration rate.

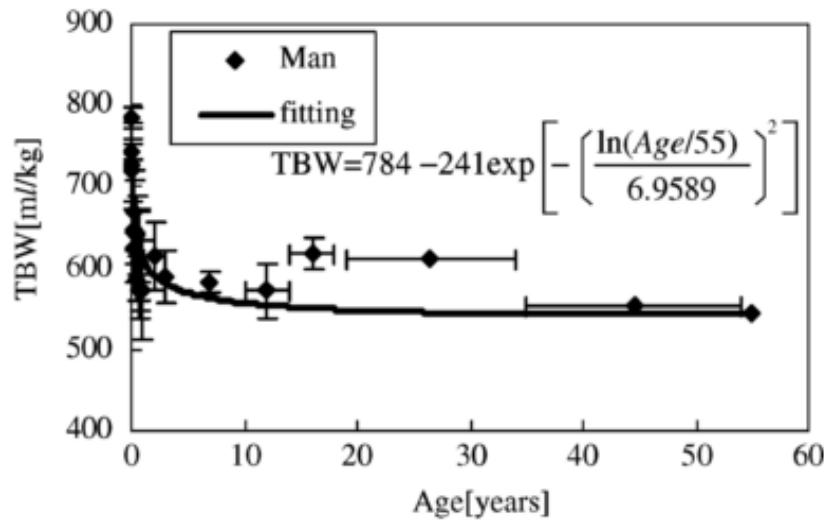
The tissue hydration rate, as a function of TBW and mass density  $\rho$ , is expressed by the relation:

$$\alpha = \rho \cdot TBW \quad (9)$$

Even though the other compounds, organ specific ones, vary with age, for simplification is considered that only hydration rate is age dependent.

The mass density is not considered as a function of age, therefore the only parameter that reflects change with age is TBW, while TBW variation with age has to be quantified in order to derive expression/formula that gives permittivity as a function of age.

Wang at al.[14] has proposed the fitting function for TBW which tends to fit values of TBW as a function of human age, values published by Altman and Dittmer on 1974 [17].



**Figure 9.** Fitting function for TBW [14]

After few mathematical operations the formula for calculating complex tissue permittivity is extracted, as a function of tissue hydration rate, adult tissue permittivity and adult tissue hydration rate:

$$\varepsilon_r = \varepsilon_{rw}^{\frac{\alpha - \alpha_A}{1 - \alpha_A}} \cdot \varepsilon_{rA}^{\frac{1 - \alpha}{1 - \alpha_A}} \left( 1 - j \frac{1}{\omega \tau} \right) \quad (10)$$

$\alpha$  - child biological tissue hydration rate

$\alpha_A$  - adult biological tissue hydration rate

$\varepsilon_{rA}$  - relative permittivity of adult biological tissue

Even though it is a very good approach on finding dielectric parameters of humans at different ages, the following remarks need to be raised up: Fitting function values deviate considerably from experimental measurements for some ages and according to figure the TBW varies at great extent under 3 years old but becomes insignificant for ages over 3 years old.

The very important aspect is the formula validation. Wang et al. [14] report validation of formula by checking validity using Peyman et al. [8] measured data for rats. The difference of results obtained with formula and measure data for rats were within  $\pm 20\%$  for all the tissues in the young rats, thus empirical formula proposed by Wang is therefore the reasonable representation of age-dependent tissue dielectric properties.

### 3.2. Dielectric parameters of 3 months-13 year's old boys biological tissues

Wang et al. [14], as described on previous paragraph, derived an empirical formula for the calculation of age dependency of permittivity and conductivity of human biological tissues as a function of the total body water content (TBW), where TBW values were taken from Altman and Dittmer [17] measurements of year 1974.

As reported in [18], secular trends in the nutritional status of infants and children alter the relation between age or weight and TBW, thus equations proposed in previous decades overestimated TBW in all age groups, including children.

TBW at humans has changed from year 1974 and especially in children. There are lately revised formulas that give relation of TBW as a function of child height and weight.

Therefore, in [19] we propose the formulas for calculation of permittivity and conductivity of children biological tissues as a function of children weight and height, respectively age, whereas child TBW values are calculated with formula presented on [18].

Children biological tissues are composed mainly of water, thus for simplification reason they may be considered as given by two composites, water and organ specific tissue. Even though concentration of other compounds, organ specific ones, may also vary with age, for simplification purpose we assume that organ specific part is not age dependent, while main part of biological tissue TBW changes as a function of age.

For the child biological tissues, permittivity can be expressed as:



$$\varepsilon_{rch} = \varepsilon_{rw}^{\alpha_{ch}} \cdot \varepsilon_{r0}^{1-\alpha_{ch}} \quad (11)$$

$\alpha_{ch}$  - Child biological tissue hydration rate

Following mathematical operations, as described at Wang et al. [14], permittivity as a function of hydration rates, respectively child and adult TBW, can be formulated as:

$$\varepsilon_{rch} = \varepsilon_{rw}^{\frac{\alpha_{ch}-\alpha_A}{1-\alpha_A}} \cdot \varepsilon_{rA}^{\frac{1-\alpha_{ch}}{1-\alpha_A}} \quad (12)$$

Lately, the Mellits and Cheeks formula for the determination of child TBW has been reformulated. According to [18], child TBW in liters for age 3-month-old to 13-year-old boys can be expressed as:

$$TBW = 0.0846 (Height \cdot Weight)^{0.65} \quad (13)$$

For girls for age 3-month-old to 13-year-old the TBW is expressed as:

$$TBW = 0.0846 * 0.95 (Height \cdot Weight)^{0.65} \quad (14)$$

When replacing TBW for boys on above equations and after few approximations we derived formulas (15) and (18) that were presented in [19].

In order to derive formulas we made some approximations. For tissues, we considered mass density 1,071 g/ml that might be taken as an average of mass density for most tissues, but not all of them. Some organs, such as lungs, do have mass density that differs significantly, up to 3 times, from the taken average value. For such tissues the proposed formula needs to be adopted.

In order to find approximate adult hydration rate, and take it as a constant in formula, we assume adult weight as 75 kg and TBW as 41.9 liters. Based on measurements conducted on [20], 41.9 liters corresponds to a man who is 20-29 years old.

For relative permittivity of water the value of 74.3 at 37 Celsius is taken [21].

Presented formulas express the relative permittivity of child biological tissue as a function of child height and weight and a function of an adult relative permittivity.

The formulas are considered valid if we refer other values of adult TBW and weight that do not reflect significant change of adult hydration rate.

$$\varepsilon_{rch}(X) = 2.616^{(X-6.63)} * \varepsilon_{rA}^{2.4813(1-0.09X)} \quad (15)$$

The variable X is introduced to simplify the formula in terms of its dependence on child height and weight:

$$X = \text{Height}^{0.65} * \text{Weight}^{-0.35} \quad (16)$$

Referring to relation (3), the conductivity of tissue as function of relative permittivity may be expressed as:

$$\sigma_{ch}(X) = \frac{10^{-9}}{36\pi\tau} \varepsilon_{r_{ch}}(X) \quad (17)$$

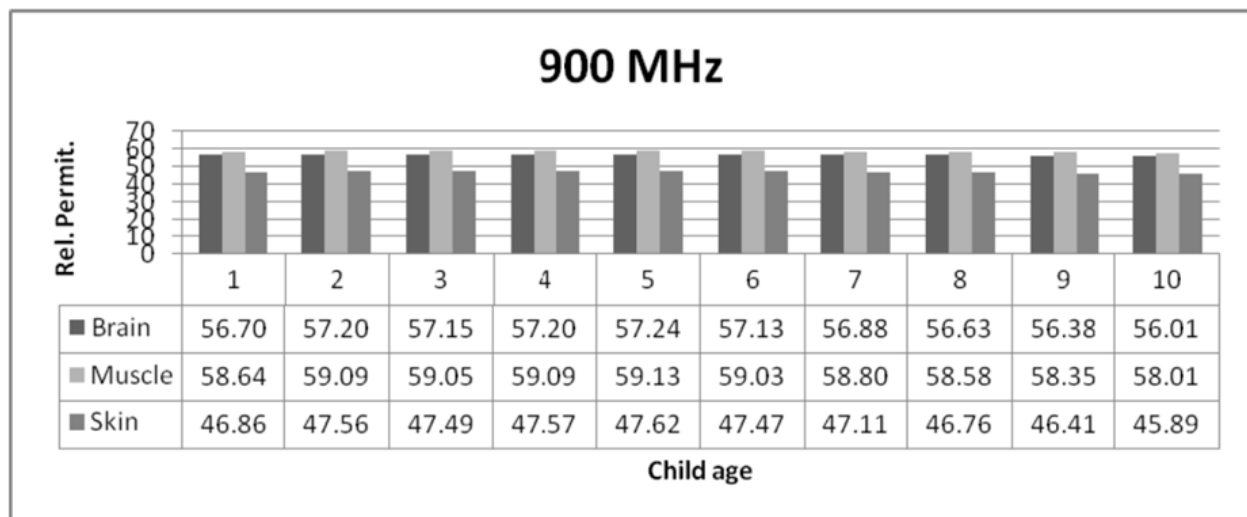
Replacing relation (15) on (17) the following relation for conductivity is obtained:

$$\sigma_{ch}(X) = \frac{10^{-9}}{36\pi\tau} \varepsilon_{r_{ch}}(X) = 2.616^{(X-6.63)} * \varepsilon_{r_A}^{2.4813(1-0.09X)} \quad (18)$$

With the formula (15) and (16) the values of permittivity of child bio tissues are calculated and presented in Figures 10-11.

Adult tissue relative permittivity values were taken from [5] while child height and weight were taken from World Health Organization growing charts, as 50<sup>th</sup> growing percentiles [22].

The advantage of the proposed approach is the calculation of dielectric parameters, conductivity and permittivity, for biological tissues of children of specific height and weight.



**Figure 10.** Children's relative permittivity at 900 MHz

The results are presented for brain, muscle and skin for children aged 1-10 years old, boys, for frequencies 900 MHz, 1800 MHz and 2.4 GHz.

From Figures 8-10, it can be easily extrapolated the difference between biological tissue dielectric parameters of end ages, 1-year-old and 10-year-old children, but it can be also made a comparative analysis between the permittivity of the same child age but different biological tissue.

Even though the values at different frequencies change, the similar variation trend of tissue permittivity as a function of age is noticed for all microwave frequencies

If we compare obtained permittivity values among different tissues, we notice that highest values are obtained for the muscle and the lowest ones for the skin.

It should be mentioned that height and weight were taken as 50<sup>th</sup> growing percentiles in relation age- (height and weight) while the methodology for extracting values for other growing percentiles remains unchanged.

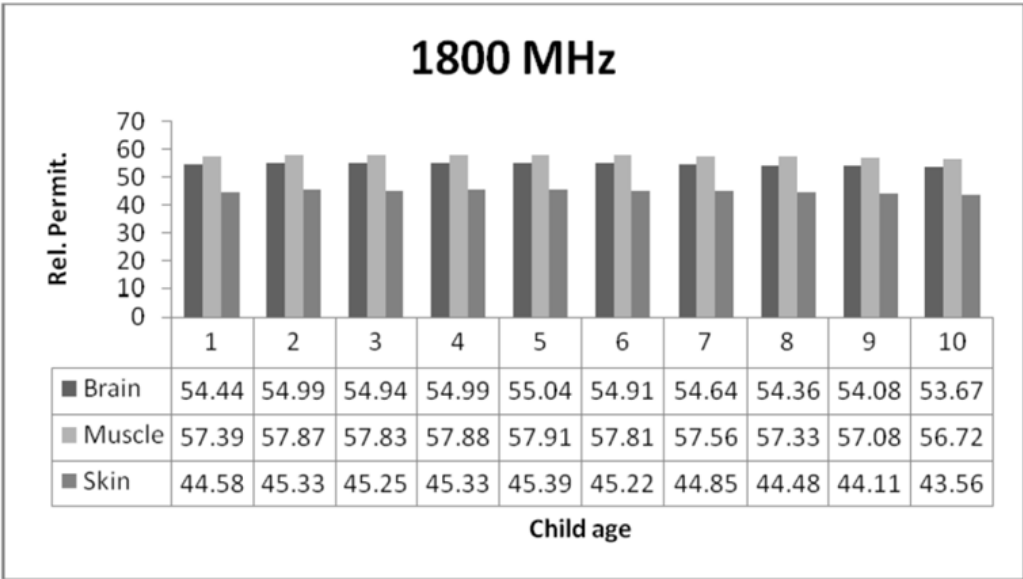


Figure 11. Children’s relative permittivity at 1800 MHz

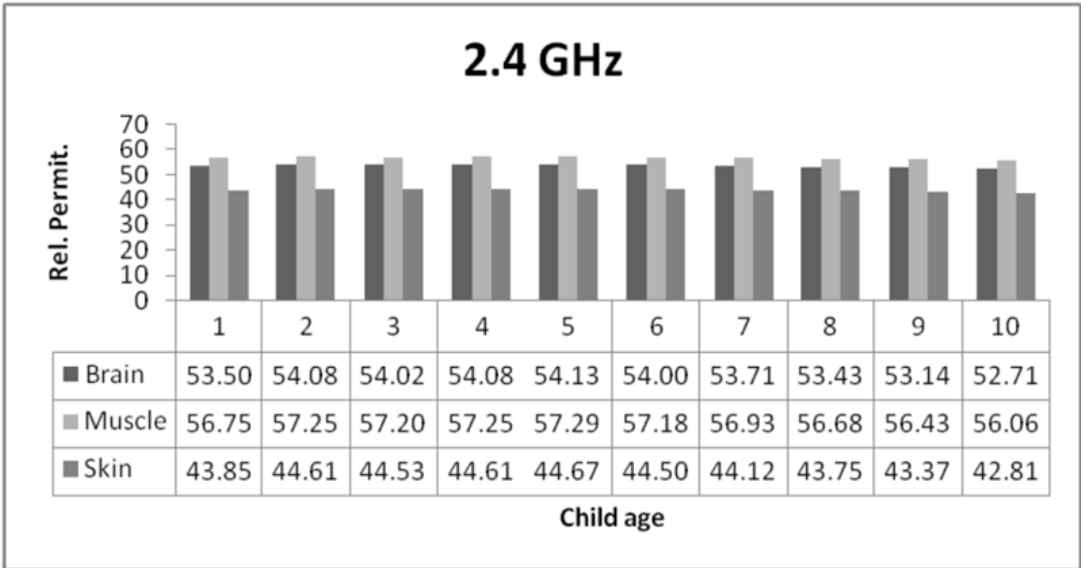
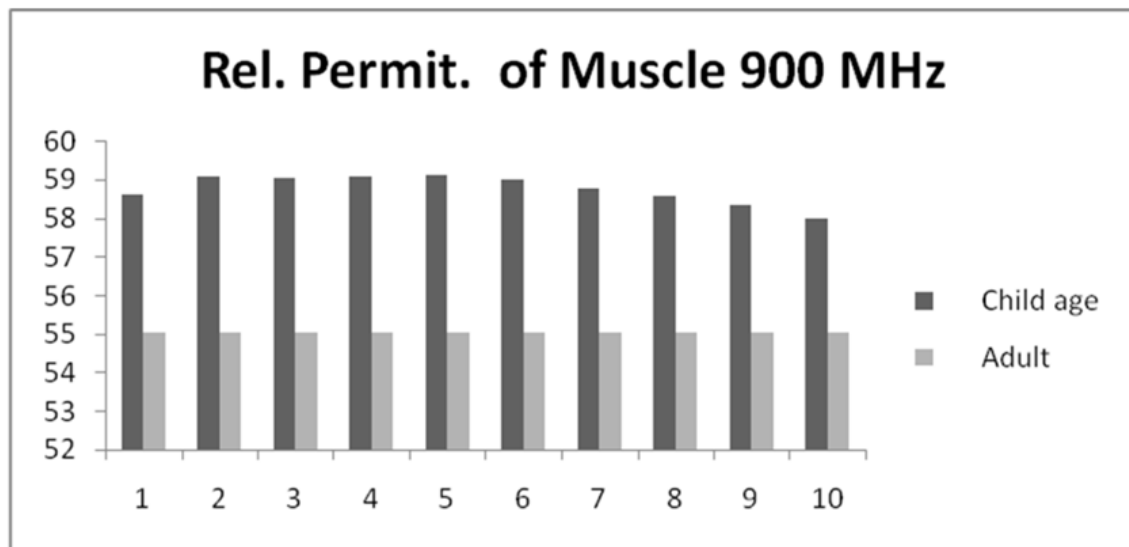


Figure 12. Children’s relative permittivity at 2400 MHz

After obtaining results for children biological tissues dielectric parameters, the comparison between obtained values and adult bio tissues dielectric parameters can be conducted.

In Figure 13 is presented only one example of comparative analysis, namely the differences on muscle permittivity for frequency 900 MHz.



**Figure 13.** Child vs. adult relative permittivity at 900 MHz

It should be pointed out that all obtained values of children dielectric parameters are results of proposed theoretical approach which needs experimental validation; therefore the proposed formulas need experimental validation.

The aim of the study was to confirm age-dependence of dielectric parameters and to verify that child dielectric parameters differ from adults and they should not be taken as the same in the dosimetric research, as many research studies have done so far.

The knowledge of dielectric properties for humans at different age is important as well to create body-simulant materials that will be used for electromagnetic measurement applications. These materials should have dielectric properties that mimic those of human tissues [23].

The human body is composed by multilayered tissues, dielectric parameters of each of them vary with age, some more some less. For simplification purpose multilayered tissues can be simulated by one homogenous liquid whose dielectric properties match those of the tissue that is of most interest [24].

Beside comparative analysis between children and adult dielectric parameters of biological tissues, the very limited comparative analysis between child tissues permittivity obtained by different studies was conducted.

As noticed in the Figures 14-15, there is a good agreement between values obtained by different studies.

Nevertheless the comparative research should be more inclusive conducted for more tissue in order to come to exhaustive conclusions.

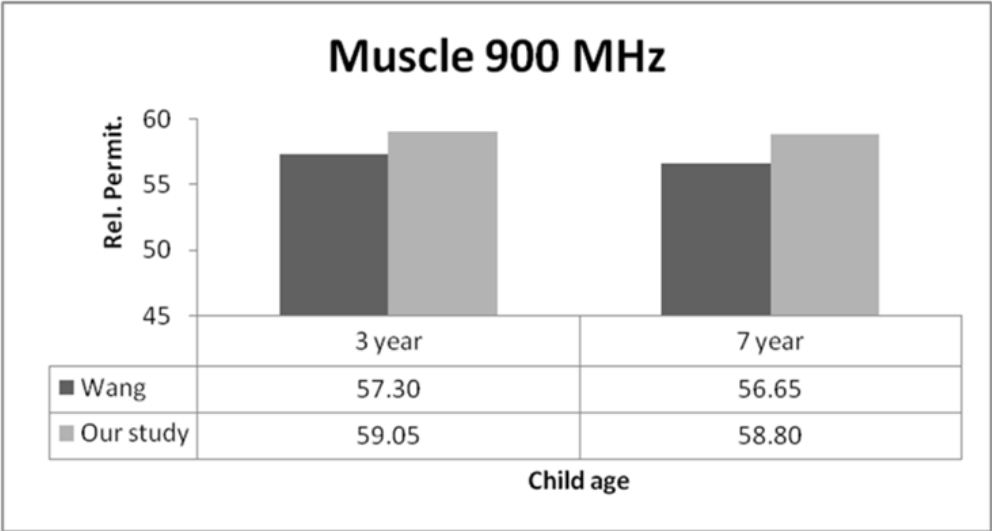


Figure 14. The child permittivity obtained by two studies

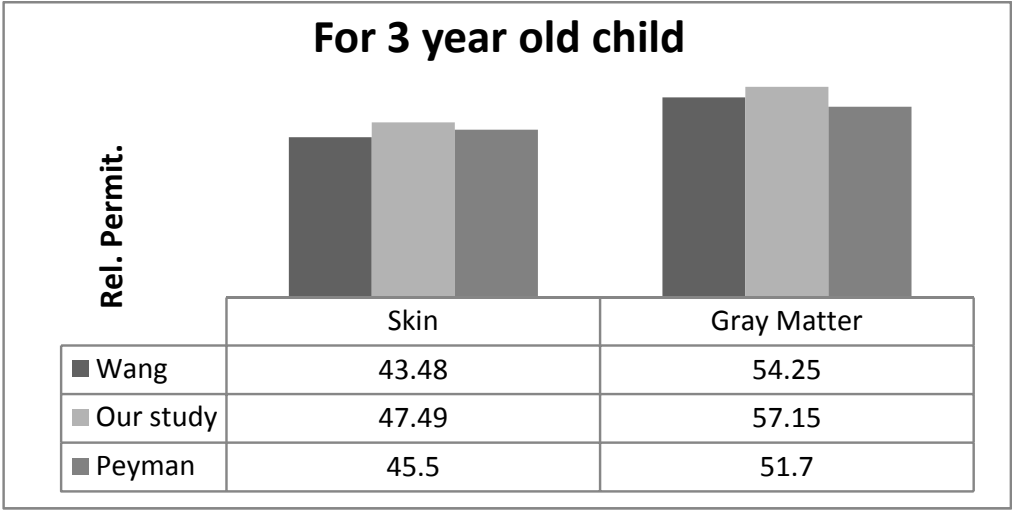


Figure 15. The 3-year old child permittivity obtained by three studies

4. Conclusions

The confirmation of age-dependence of dielectric parameters of human biological tissues potentially may contribute on issue whether children should be considered a sensitive group in comparison to adults regarding exposure to microwave electromagnetic fields, issue that still remains debatable at scientific forums.

Experimental measurement *in vivo* at most human biological tissues is impossible, thus alternative methodologies have to be considered, few of them mentioned on this chapter.

Extrapolation of obtained experimental results of dielectric parameters of animal bio tissues to humans is considered debatable since animal tissues differ significantly from human tissues, and a detailed and all –inclusive study of animal and human growing curves along with markers along curves should be performed to propose correlation between animal and human dielectric parameters.

Thus, presenting the empiric formulas for estimating permittivity and conductivity of human biological tissues as a function of age is to be considered as a reasonable solution for the issue even though the each proposed theoretical approach needs experimental validation, which is very limited due to available measuring techniques.

Since biological tissues are dominantly composed of water content, their dielectric characterization is a function of TBW- a parameter that changes with age. This has triggered researchers to propose formulas for estimating permittivity and conductivity of human biological tissues as a function of age, respectively TBW.

The results presented in the chapter, with all covered methods, confirm that permittivity and conductivity of human tissues are age-dependent, presenting also change trend over age.

The limited comparative analysis shows a satisfactory agreement between results obtained with different approaches.

Nevertheless it should be pointed that results presented with theoretical approach are not experimentally validated, so they should be taken with reserve by the scientific community. As a matter of fact, the aim was to confirm the variation trend of permittivity and conductivity with age and not to present precise values of microwave dielectric parameters of human tissues for each human age.

Experimental validation of theoretical approaches for derivation of dielectric parameters of human tissues as a function of age, detailed comparative analysis of obtained results by different studies, assessment of difference between dielectric parameters of males and females at each age, are just a few of issues that remain open for further research.

## Appendix

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