



Research Article

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# The Possibility of Concentrating Microwave Radiation at Certain Points of the Endothelium of Blood Vessels

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## Abstract

**Purpose:** The main purpose of the study is to show that the connective tissue forming the inner surfaces of blood vessels can be a concentrator of an electric field.

**Material and Methods:** Previously, when studying the effects of electromagnetic fields and radiation on the human body, only thermal processes were taken into account. In this case, the calculated SAR method and the experimental method of tissue equivalent phantom dummies were used, as a rule. Also, their implementation assumed, as a rule, that the absorbing medium is single-phase. This did not take into account the effects associated with the fact that biological tissue is a mixture of components whose dielectric permittivity differs tenfold, and the particle sizes of the phase components, as a rule, do not exceed one millimeter. The article presents the results of using a computer model that makes it possible to analyze the uneven distribution of the electric field in blood vessels. Computational experiments were performed using the author's computer program based on the finite element method.

The structure of the tissue containing blood capillaries was imitated by matrix systems containing cylindrical inclusions, the sections of which were characterized by round and rectangular shapes. Computer experiments have been carried out to calculate patterns of spatial distributions of electric field strength. The values of the dielectric constant of the matrix and inclusions, the relative sizes and relative positions of the inclusions varied. The processes were considered stationary and axisymmetric.

**Results:** It was found that blood vessels can focus the external electric field of microwave radiation on some points of their internal surfaces. The degree of concentration is characterized by the parameter  $k = E/E_0$ , which is equal to the ratio of local tension to the average for the tissue. A significant anisotropy of the concentration effect was found. If the microwave radiation is directed perpendicular to the axis of the cylindrical vessel, the field strengths inside the capillary and in the surrounding tissue are close to each other, there is no concentration effect. If the external field is directed perpendicular to the capillary axis, there is a significant (tens of times) concentration of tension in the connective tissue surrounding the vessel. It was found that the most significant concentration ( $k > 40$ ) occurs in the areas of vascular branching.

**Conclusion:** 1). The obtained results can be used in the analysis of the results of the pathological effects of electromagnetic waves on the human body. 2). Attention is drawn to the fact that the endothelium, which performs a number of important physiological functions, falls into the area of concentration of electric field strength. It is suggested that the effect of an electric field on the endothelium can create both carcinogenic and physiological effects due to physico-chemical processes initiated by an electric field characterized by high intensity values. 3) It must be borne in mind that the electrical component of the electromagnetic wave fluctuates in time and direction. Therefore, the action under discussion is carried out locally, briefly and significantly, like a sewing machine needle.

**Keywords:** Non-ionizing radiation, Multiphase human tissues, blood vessels, Electromagnetic field, Finite element method, Concentration of electric fields, Endothelium

## Introduction

In the last fifteen years, a belief has been formed about the harmful effects of cellular communications on the human body. In particular, in [1], a statistical analysis of the dynamics of the occurrence of malignant brain tumors in patients diagnosed in 1997-2003 and 2007-2009 was carried out. The highest risk of

developing the disease was associated with the temporal lobe. The authors found an increased risk of developing glioma due to an increase in the use of a mobile or wireless phone during this time period. The correctness of the analysis was confirmed by a number of other works, see, in particular, [2].

Similarly, evidence of the influence of cellular communication on human thyroid oncogenesis is presented in [3,4].



Children are currently the most important object of exposure to electromagnetic fields. It has been shown [5,6] that the health of children (6-10 years old) and adolescents (11-16 years old) is at particular risk due to the chronic influence of cellular communications. It has been established that health disorders in children and adolescents can manifest themselves in asthenic syndrome (headache, irritability, fatigue, sleep disorders, periodic pain in the heart and joints); mental maladaptation (anxiety, stress, depression, etc.), as well as in their combination. Along with the above-mentioned syndromes, the effects of RF EMF exposure manifest themselves as indirect signs of impaired memory and attention, such as forgetfulness (inability to recall necessary information in time) and inattention (inability to focus on a phenomenon or activity), and even as an increase in the frequency of colds.

The general problems of exposure to electromagnetic fields were discussed in [7]. Attention is drawn to the sharp increase in the power of sources of electromagnetic fields in human activity. The authors of the cited work pointed out that over the past 50 years, the daily power of radio emissions has increased by a total of more than 50 thousand times.

The technical sphere of human activity plays a special role in the overall increase in harmful effects of electromagnetic radiation. The growth of electromagnetic radiation, characteristic of modern industry, is reflected in the growth of occupational diseases. At the same time, in [8], a mathematical analysis of the features of cardiovascular diseases of female employees of the Surgut gas condensate plant was carried out. In [9,10], the relationship between exposure to radiation from factory and ship radar stations and the frequency of cardiovascular diseases of service personnel is shown. In [11,12], the harmful effects of the electromagnetic field of transformer substations are indicated.

It has been established that a common form of damage to the organ of vision is microwave-induced cataract as a result of both chronic and single intensive exposure [13].

It should be noted that there is also a point of view that denies the existence of a link between the development of cellular communications and an increased risk of cancer. In [14,15], no stable, strong relationship was found between microwave exposure and adverse health effects. It was concluded that there is only weak evidence and currently there are no sufficient grounds to define microwave as dangerous to health. Of course, it is necessary to find out how well-founded the proposed doubts about the harmfulness of radiation are. The most important argument should be the identification of the mechanisms of possible effects of electromagnetic fields on living tissue.

What is the possible cause of possible exposure to electromagnetic radiation? An analysis of the available literature shows that the researchers paid the greatest attention to the thermal effect of an electromagnetic wave. The discussed effect is well known and, in particular, finds wide useful application in the practice of cancer treatment [16,17]. Therefore, the most appropriate explanation for the causes of possible exposure related specifically to the heating of tissues.

In this case, experimental methods were used, first of all, involving the use of phantoms containing bioequivalent tissue and embedded thermo-sensors. In addition, computational numerical methods were used to evaluate the heating of bioequivalent tissues of various parts of the human body [18]. The process of heating living tissue by microwave radiation is usually characterized by the SAR (Specific Absorption Rate) value [19,20]. It is equal to the ratio of the power absorbed in a given cell to the weight of the biological tissue in it. When calculating SAR, the values of the electric field strength  $E$ , as well as the electrical conductivity  $\sigma$  and the density of biological tissue  $\rho$  were used.:

$$SAR = \sigma |E|^2 / \rho \quad (1)$$

The values of the intensity  $E$  can be obtained by computational methods based on the finite element method and the finite difference method [18]. However, it should be noted that earlier experiments on phantoms and SAR calculations assumed the presence of a single-phase bioequivalent tissue. In particular, the presence of individual blood vessels is largely ignored. Meanwhile, the local value  $E$  significantly depends on the dielectric constant of the medium  $\epsilon$ . It should be borne in mind that  $\epsilon$  differs tenfold for blood and connective tissue.

Next, it should be noted the hypothetical existence of non-thermal effects of electromagnetic waves, that is, the effect of a "pure" electric field. In the last decade, a number of mechanisms of the non-thermal effect of electromagnetic radiation on water have been discovered. First of all, it was found that both stationary electric and microwave wave fields significantly change the physico-chemical properties of water, which is one of the main components of a living organism. It has been shown that irradiation leads to a decrease in resistivity, a change in the viscosity coefficient and reactivity of distilled water [21,22]. It was found in [23] that irradiation leads to an increase in pH and a change in the IR absorption spectra of distilled water. A number of new results are reflected in the materials of the annual conference held by the Institute of IOF RAS (see, in particular, [24]).

Summarizing the above review of the literature data, the following conclusions can be drawn. When studying the effects of microwave electromagnetic fields on the human body, the main attention was paid to the study of thermal processes occurring in single-phase media simulating living tissue. It seems necessary to develop new research methods in the field under discussion. According to the author, an important problem of the experimental study of the propagation of electromagnetic fields in multiphase biological objects is that the particle sizes of the phase components are in some cases on the order of microns. In addition, the introduction of probes into the tissue, even micron-sized ones, should significantly perturb both the electric field of the wave and the functional state of the body.

According to the author of this paper, computer modeling of the propagation of electric fields in micron-homogeneous systems provides additional opportunities for studying multiphase objects characterized by micron-sized components. Computer modeling allows us to take into account that the phase components of

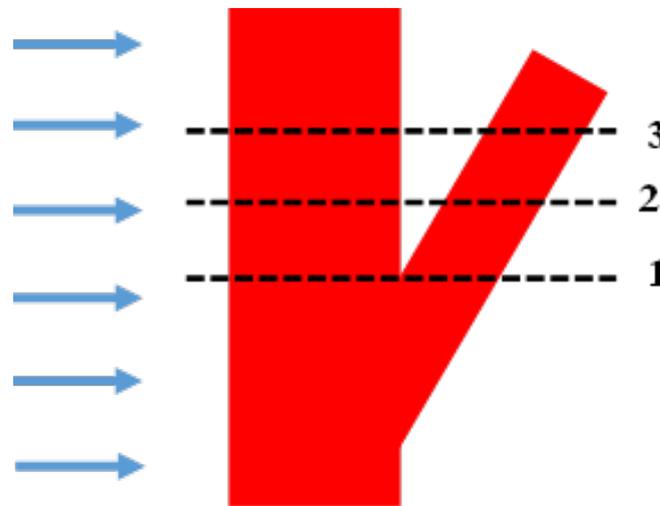
living tissue vary significantly in terms of the dielectric constant, as well as in the shape of the particles and the relative position of the particles. In fact, living tissue is a kind of composite material consisting of components characterized by dielectric permittivity, varying tenfold. It is advisable to use computer techniques that were previously well developed for technical materials to study the properties of living tissue (see, in particular, [25]).

## Material and Methods

Consider a tissue containing a system of blood vessels and capillaries. Let's take into account the presence of vascular branching areas. An illustration of the system under consideration is shown in Figure 1. The red color corresponds to a vessel containing blood, and the white color corresponds to connective

tissue. The flow of the electric field strength vector  $E$ , shown in Figure 1 with the blue arrows, propagates through the region under consideration. In reality, the source of the field may be the electrical component of an electromagnetic wave. We will limit ourselves to considering situations in which the wavelength of radiation is much larger than the diameters of vessels or capillaries. In this case, the vortex nature of the field can be neglected. Previously, a similar object was considered in the article [26], presented in Russian. However, it did not take into account the possibility of branching of blood vessels. One of the purposes of this article is to show that the area of vascular bifurcation is one of the most dangerous targets for electromagnetic radiation.

Let's make a section of the blood vessel with planes 1,2,3 perpendicular to the axis of the main vessel shown in Figure 1.



**Figure 1:** Axial cross-section of the considered section of the blood vessel containing the branching area.

In this paper, we will limit ourselves to considering situations in which the vector of an external undisturbed electric field is perpendicular to the axis of the main blood vessel.

Note that water and blood have a dielectric constant that is ten times higher than that of other connective tissue components. It can be expected that in such a heterophase system there should be a significant spatial heterogeneity in the distribution of electric field strength, [25]. Let's idealize the object of research. In reality, living tissue is characterized by a rather complex phase structure. In order to find out only the general patterns of electric field propagation in such an environment, we simulate sections of vessels and capillaries with cylindrical volumes. We further assume that the connective tissue containing the circulatory system is single-phase.

Let's make a section of the area under consideration with planes 1, 2 and 3 perpendicular to the axis of the main vessel, differing in position relative to the bifurcation area. They are represented in Figure 1 by dashed lines. Let us consider two-dimensional processes of electric field propagation in these sections.

The relative dielectric permittivities of connective tissue and blood are considered to differ by an order of magnitude and equal to  $\epsilon_m$  and  $\epsilon_i$ , respectively.

We will limit ourselves to considering situations common in practice when the length of an electromagnetic wave turns out to be much larger than the diameter of a blood vessel. We consider the processes of electrical relaxation to be quite fast, in comparison with the oscillation period of the wave. Under the described conditions, the electric field can be considered potential and stationary. The model does not take into account the blood flow in the vessels, since it does not affect the intensity of the electric field.

The aim of the work is to obtain a general, characteristic picture of the spatial distribution of the electric field strength  $E$ , realized under the conditions under consideration. To solve the problem, we apply the numerical finite element method. We use a computer program created by the author in the Fortran language. The description of the technique was presented in [25-27].

The use of the Fortran language provided high calculation efficiency and the possibility of subsequent integration with other stand-alone programs and the possibility of further study of various scenarios of tissue degradation.

Note that the propagation of an electric field in the considered multiphase medium can be considered as a process of electric field transfer, in which the dielectric constant  $\epsilon$  is the transfer coefficient, and the local magnitude and direction of the voltage vector  $E$  are

determined by the spatial distribution of the electric potential  $\varphi$ ,  $E = -\text{grad}(\varphi)$ . To find  $\varphi$ , we use a variational formulation of the transfer equations (see [25-27]). We use the condition of extremality of the functional:

$$\chi = \int_V \varepsilon (\text{grad}\varphi)^2 dV, \quad (2)$$

where  $\varphi$  is the electric potential,  $\varepsilon$  is the local conductivity (dielectric constant),  $V$  is the volume of the calculated area,  $dV$  is the element of its volume. The functional  $\chi$  has the meaning of entropy production, while  $(\text{grad}\varphi)$  and  $(\varepsilon \text{grad}\varphi)$  play the role of thermodynamic force and thermodynamic flow, respectively. Next, we use the formalism of the finite element method with the discretization of the medium by triangular simplex elements.

Rectangular cross-sectional areas containing round and rectangular inclusions with arbitrary dielectric permittivity, size and position were used as the calculated area  $V$ .

## Calculation Results

In this paper, computational experiments have been conducted to study the geometric features of the spatial distributions of electric field strength,  $E(x,y)$ , realized in living tissue containing

blood capillaries. The calculations were performed on grids with a partition density of 200 x 200 elements.

The error in calculating the values of the electric potential was estimated using the methods described in detail in [25-27]. They are based on the reproducibility of the results of calculations performed with a different number of inclusions represented in the workspace, different partition densities, and also by using duality ratios from the outside. At the same time, only those results with a relative error of less than 0.1% were taken into account.

Let's consider the propagation of the electric field intensity flux in planes 1-3 shown in Figure 1. When systematizing the calculation results, we use the local Cartesian coordinate system  $(x,y)$ , the scheme of which is shown in Figure 2. The blue arrow on it is the direction of the undisturbed electric field  $E_0$ ,  $R$  is the radius of the main vessel,  $\Delta$  is the distance between between the surfaces of the vessels,  $0$  is the origin of the coordinate system located on the inner surface of one of the capillaries. The  $y$ -axis is oriented parallel to the direction of the undisturbed electric field, and the  $x$ -axis is perpendicular to it. In this case, dimensionless coordinates were used,  $x = X/L$ ,  $y = Y/L$ , where  $L$  is the size of the calculated area in the  $y$  direction.

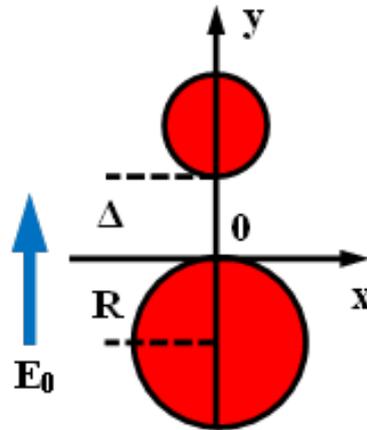
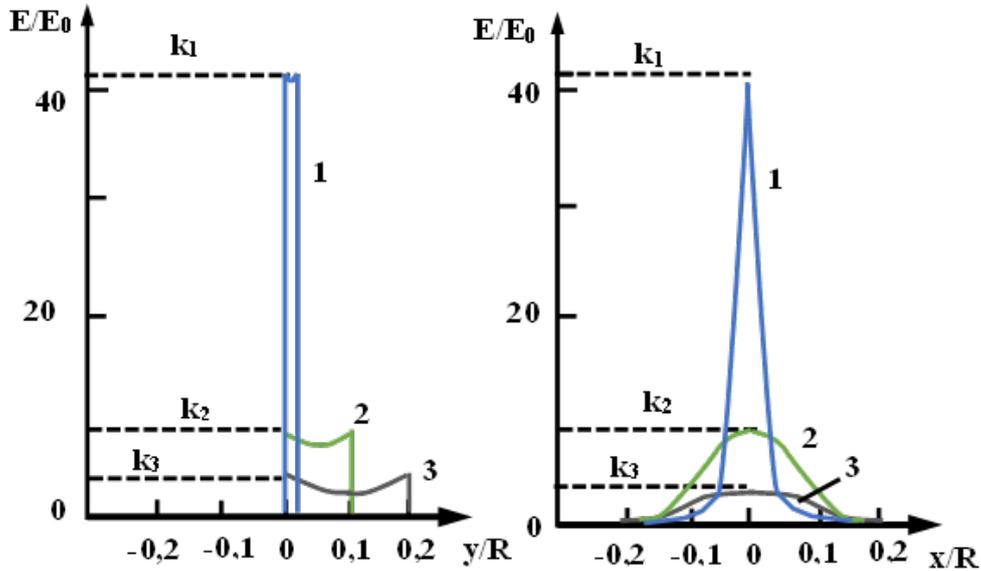


Figure 2: Diagram of the local coordinate system.

Figure 3 shows typical dependences of the relative local tension  $E/E_0$  on the values of the local coordinates  $(x,y)$  corresponding to sections 1-3 of Figure 1. Calculations were performed for the conditions:  $\varepsilon_i/\varepsilon_m = 30$  and  $\Delta/R$ , equal to 0.0, 0.1 and 0.2 for curves 1-3, respectively.

The color in Figure 3 highlights the situations of high, medium, and low electric field concentrations for sections 1-3, respectively. It can be seen that the areas of capillaries close to the bifurcation region are characterized by the greatest effect.



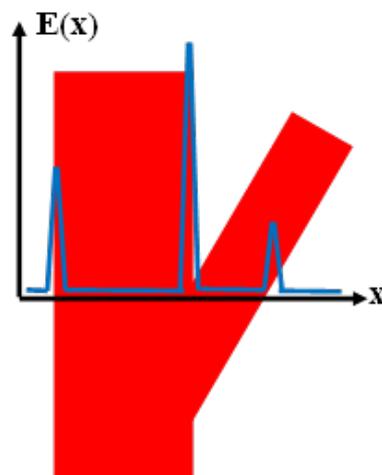
**Figure 3:** Spatial distributions of electric field strength in the axial,  $E(y)$ , and transverse  $E(x)$  directions of the external electric field at  $\Delta$  equal to 0.0, 0.1, and 0.2. for curves 1-3, respectively.

It draws attention to the fact that the external electric field is significantly transformed as a result of interaction with the spatially inhomogeneous two-phase environment of the biological tissue. In this case, under the conditions under consideration, in the direction of the  $y$ -axis, the electric field is concentrated in the space between the branches of the blood vessels. The effect of the concentration of tension is characterized by the concentration parameter  $k = E_m / E_0$ , where  $E_m$  is the maximum value of the local tension,  $E_0$  is its undisturbed value.

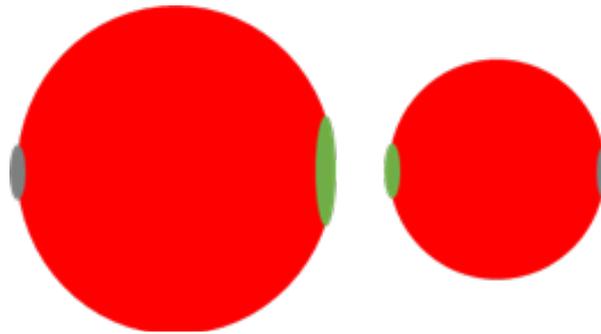
Systematization of the calculation results showed that the

maximum value of the voltage is formed at a point located on the inner surface of the capillary, in particular, at  $x = 0, y = 0$  in Figure 1. In this case, the distribution of electric field strength  $E(y)$  in the longitudinal direction has the form of a step function, and in the “transverse” direction,  $E(x)$ , is similar to a Gaussian function characterized by a dispersion close in magnitude to the capillary radius.

The features of the location of the areas in which the electric field strength is concentrated are illustrated in Figures 4, 5.



**Figure 4:** Diagram of the concentration of the electric field in the area of bifurcation of the circulatory system, for section “1”.



**Figure 5:** DDiagrams of the topographic features of the electric field concentration characteristic of section 3. The areas characterized by  $k > 20$  are highlighted in green, and  $k > 10$  in gray.

The systematization of calculations showed that the value of  $k$  does not depend on the radius of the vessel.  $R$  affects only the variance of the dependence  $E(y)$  and, accordingly, the volume of the area characterized by an increased value of tension.

## Discussion

It was shown above that, under certain conditions, electromagnetic radiation can create areas of concentration of electric field intensity on the inner surfaces of blood vessels that exceed the tissue average by tens of times.

According to the author, the most important result of this work is that the concentration of the electric field falls on the layer of endothelium covering the inner surfaces of blood vessels. It is known that the endothelium forms one of the most important organs of the body, providing the most important physiological functions. In this case, the endothelium is a layer of cells that covers the surfaces of all blood and lymph vessels, as well as the cavities of the heart. It forms an endocrine organ that performs a number of important physiological functions: regulation of blood pressure, blood clotting and fluidity, initiates the processes of injury healing and the growth of new blood vessels. It serves as a regulator of substance transport and cell migration through the vascular wall, etc., [28,30]. It has been shown [31] that it is the endothelium that is the target of the aggressive effects of the SARS-CoV-2 coronavirus.

The main factor ensuring the presence of the concentration effect is the contrast of the dielectric permittivity values of the blood and connective tissue surrounding the vessel,  $\epsilon_i / \epsilon_m$ . The effect of the concentration of the electric field is significantly enhanced for the branching areas of blood vessels. Along the way, it should be noted that record contrast values can be expected for lung tissue in the areas of the air environment, however, a more detailed consideration of the situation is beyond the scope of this work.

It was also found that the concentration effect has a significantly anisotropic character. In particular, if the electric field is directed parallel to the axes of cylindrical blood vessels, the concentration effect is not realized, the field turns out to be homogeneous and its intensity turns out to be equal to the value of the undisturbed external field,  $k = 1$ . Thus, in reality, the concentration effect is "selective" in nature and is provided only for a small number of vessels whose axes turn out to be parallel to the direction of

propagation of the electromagnetic wave, and the instantaneous direction of the voltage fluctuation vector  $E$  turns out to be perpendicular to the inner surface of the blood vessel.

The effect of the electric tension of an electromagnetic wave can be likened to a sharp needle of a sewing machine, acting periodically, with the frequency of wave vibrations, on the changing points of the inner surfaces of blood vessels.

## Conclusion

The above study shows that there is a previously unexplored possibility of exposure to microwave radiation on the endothelial layers of blood vessels. Specialized computer programs were used. The author's experience has shown a number of advantages of this approach, in comparison with the standard one. These include: the ability to dock with other programs, the ability to solve non-standard tasks, cheapness, as well as the prospects for their implementation in clinical research practice.

It has been found that blood vessels focus external electric fields on their internal surfaces. The concentration effect is most significant in the areas of vascular branching, while the local value of the electric field strength can exceed the intensity in the connective tissue by more than 40 times.

The consequences of exposure to electromagnetic fields can be both oncological diseases and endothelial dysfunctions.

The presented effects of concentration need to be confirmed through clinical studies and pathoanatomic examinations. It should be borne in mind that the areas of exposure to a concentrated electric field have the character of sharp needle-like pricks located at certain points on the inner surfaces of blood vessels. It is also necessary to take into account that only vessels whose axes are parallel to the direction of propagation of electromagnetic waves can be exposed to pathological influences.

It should also be borne in mind that a significantly idealized model of the tissue structure was used. More reliable data can be obtained using more powerful computer technologies.

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