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RESEARCH ON THE ELECTROMAGNETIC COMPATIBILITY OF MATERIALS FOR ORTHOPEDIC PROSTHETICS

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Introduction. *Acrylic plastics are widely used in orthopedic dentistry and orthodontics. They are the main material for the manufacture of various types of dental prostheses. To create an orthopedic product, a mixture of powder (polymer) and liquid (monomer) is obtained, from which a product of the required shape and size is formed and solidified. The resulting designs must meet the requirements for compatibility with living tissues, including the little-studied compatibility of the electromagnetic component.*

Main part. *Dielectric materials when heated form their own electromagnetic radiation in the millimeter range, which is a general property of heated dielectrics. By this, electromagnetic flows (EMF) of different directions arise. These flows can have a positive or negative direction and in a certain way affect the adjacent biotissues and the human body as a whole. Therefore, the authors conducted studies of electromagnetic radiation (EMR) of 6 types of acrylic plastics, determined their levels and compared them with the level of EMR of biotissues of the human body. Based on the obtained results, conclusions were drawn regarding their electromagnetic compatibility (EMC). "Colorless basic plastic" and "Vertex Implacryl" have the highest level of EMC (up to 58%), "Ftorax" and "Sinma-M" plastics have a slightly lower level (48-53%) and the lowest EMC (35-36%) is recorded in "Vertex Basio" and "Ethakryl – 02".*

Conclusions. *Compared to the level of human electromagnetic radiation, acrylic plastics and, accordingly, dental prostheses from them form negative currents in relation to adjacent biotissues. The conducted studies allow to recommend the choice of more acceptable materials for the manufacture of dental permanent and removable prostheses, as well as to determine the correlation between the emission of electromagnetic characteristics and the appearance of complications in patients during the operation of these structures.*

Key words*: electromagnetic radiation, electromagnetic compatibility, acrylic plastics, dental protheses.*

Introduction

Acrylic plastics are widely used in orthopedic dentistry and orthodontics. They are the main material for the manufacture of various types of dental prostheses [1]. Fig. 1 presents some options for constructions using acrylic plastics – from the simplest to the most complex and voluminous.

To such constructions can be directly attributed simple temporary (provisional) crowns (Fig. 1a); partial removable prostheses and complete removable prostheses (Fig. 1b); hard palate defect obturators; lined frameworks of bridge-like prostheses and orthodontic devices of various designs (Fig. 1c).

a b c

Fig.1. Samples of orthopedic constructions using acrylic plastics:
a – a single provisional crown; b – complete removable denture of the teeth of the upper jaw; c – orthodontic plate

According to the chemical structure, acrylic plastics are represented by derivatives of acrylic (CH2=CH-COOH) and methacrylic (CH2-C(CH3-COOH)) acids and their complex ethers [1]. For the convenient use of plastics in orthopedic dentistry, manufacturers mainly create materials consisting of powder (polymer) and liquid (monomer). When powder and liquid are mixed, high-molecular compounds are formed – polymers (long linear or branched chains formed from a large number of repeating monomer units – the same or different atomic groups). From a mixture ("dough") of polymer and monomer orthopedic products are formed.

The technical properties of polymers depend on the nature, composition and purity of monomers, synthesis technology, value of molecular weight, shape of the chain, degree of its flexibility and value of connection forces.

According to the purpose, conditions of use and processing, plastic materials must have the following characteristics [2, 3]:

- sufficient strength and proper elasticity, which ensure the integrity of the prosthesis, without its deformatio n under the influence of chewing loads;
- resistance to bending and compression;
- high impact resistance;
- low specific gravity and low thermal conductivity;
- sufficient hardness, resistance to abrasion;
- bioinertness to tissues of the oral cavity, teeth and the body as a whole;
- indifference to the influence of saliva and various food substances;
- color resistance to the influence of light, air and other environmental factors;
- lack of adsorption capacity for food substances and microflora of the oral cavity.

The above characteristics of acrylic plastics have been sufficiently studied by various authors and are taken into account in practical dentistry. Failure to comply with the specified requirements can be the cause of various complications when using prostheses based on acrylic plastics.

The tissues of the prosthetic bed are the first to react to the action of the bases of the prostheses, because the mucous membrane is phylogenetically not adapted to the transmission of chewing pressure, self-cleaning, and so on. The base of the prosthesis can cause a side effect on the tissues of the prosthetic bed: a toxic, allergic and traumatic effect.

The side effect of a removable prosthesis occurs as a result of the transmission of chewing pressure on the tissues of the prosthetic bed, which is an excessive irritant for the mucous membrane, in the violation of self-cleaning, thermoregulation, articulation, taste perception. The "greenhouse effect" and the vacuum must also be attributed to the results of the side effect. The "greenhouse effect" occurs as a result of a violation of thermoregulation of the mucous membrane of the oral cavity. This phenomenon occurs due to the fact that acrylic plastics have poor thermal conductivity. It is for this reason that a higher temperature occurs under the plastic base than directly in the oral cavity, close to the temperature of the human body. A thermostat phenomenon occurs, which creates ideal conditions for the reproduction of pathogenic microorganisms and fungal microflora.

Toxic stomatitis occurs as a result of the toxic action of the acrylic bases of complete removable prostheses. There are two types of toxic stomatitis. The first is caused by a significant amount of residual monomer that did not enter the polymerization reaction. The second type of stomatitis is caused by toxins released by microorganisms and is observed in case of poor oral hygiene.

The main factor in the occurrence of acrylic toxic stomatitis is the monomer, which by its chemical structure is the methyl ether of methacrylic acid. In high concentrations, the monomer is a protoplasmic poison. It has an extremely negative effect not only on the mucous membrane of the oral cavity, but also on the whole body. Also, the cause of toxic stomatitis can be the free monomer released during the use of orthopedic structures, namely during the depolymerization process.

Allergic stomatitis can be caused not only by the monomer, but also by other additional substances used for the manufacture of prostheses – hydroquinone, benzoyl peroxide, zinc oxide, and dyes. It is difficult to single out one specific ingredient as the main cause of allergic stomatitis. Substances that cause a contact allergic reaction do not have a protein nature. They get these properties by chemically combining with body proteins. Such substances were calledhaptens. Traumatic prosthetic stomatitis is observed quite often. This is especially evident in the first days of using removable prostheses. Traumatization of the mucous membrane by the edge of the prosthesis at the border of the prosthetic bed is the basis for the formation of haptens.

Considering the presence of electromagnetic radiation in dielectrics, which are orthopedic structures made of plastic, it can be assumed that this action can also be the cause of complications in patients. That is, the given list of requirements for acrylic materials as dielectric materials should include such a parameter as electromagnetic compatibility with adjacent biotissues. The effect of electromagnetic interaction occurs on biotissues adjacent to the prosthesis under the influence of human body temperature. Determining the parameters of this interaction is an urgent task, therefore the purposes of this study is:

- determination of the radiation capacity of the most common plastic materials used for the manufacture of prostheses;
- comparison of the level of radiation of the studied samples with the level of radiation of the human body;
- determination of the level of electromagnetic compatibility of plastic orthopedic structures and the human body.

Theoretical part

Dielectric materials when heated form their own electromagnetic radiation in the millimeter range, which is a general property of heated dielectrics. The level of this radiation (*P*) is determined by the heating temperature (*T*) and the emissivity of the material. These parameters are related by the well-known Nyquist formula

$$P_{\Sigma} = \beta kT\Delta f_{RS}, \quad (1)$$

where: P_{Σ} – integral radiation power measured by a radiometric system with an analysis band Δf_{RS}, k – Boltzmann's constant $1{,}38\cdot10^{-23}\ J/K$; T – thermodynamic temperature of the research object; Δf – frequency band, analysis (measurement) of the radiometric system (RS)

From the course of thermodynamics, it is known that the coefficient of emissivity for an absolute black body (ABB) is equal to β = 1.

The level of ABB radiation at a human body temperature of 310K and the analysis band of the radiometric system $\Delta f_{RS}=10^8$ Hz, calculated according to formula (1), is $P_{ABB} = 4{,}2\cdot10^{-13}$W. The level of ABB radiation at a human body temperature of 310 K and the analysis band of the highly sensitive radiometric system $\Delta f_{RS}=10^8$ Hz, calculated according to formula (1), is $P_{ABB} = 4{,}2\cdot10^{-13}$ W.

Using Kirchhoff's formula, it is possible to calculate the emissivity coefficients of the studied materials β_M

$$\beta_M = P_M / P_{ABB}, \quad (2)$$

where P_M – radiation power of a sample of the material under study, measured by RS; P_{ABB} – calculated power.

Dielectric materials should also include bones, liquid fractions of blood and plasma, as well as orthopedic and dental dielectric implants, so as those created by bioengineering and nanomedicine technologies. This fully applies to acrylic plastics and products made from them.

The radiation power of the dielectric materials of implants, at a human body temperature of 310 K, is small (10^{-13} – 10^{-14} W), but due to the difference in the radiation of two contacting bodies (implant and biotissue), electromagnetic flows (EMF) of different directions arise. These flows can have a positive or a negative direction and in a certain way affect the adjacent biotissues and the human body as a whole. The body's reaction, despite such a low-intensity level of signals, is confirmed by laboratory studies [4].

Therefore, the study of the interaction of low-intensity microwave radiation of implanted materials with the human body, including biomedical materials, is an urgent task for specialists in various fields - biologists, doctors, physicists, developers of radio technical devices and appliance engineering. It is important to determine the electromagnetic compatibility (EMC) of implanted materials in the process of such research. The evaluation of this indicator can be carried out by appraising the coefficients of the radiation capacity of the implant material and biotissue, comparing their radiation levels.

The list and features of the studied acrylic materials

Dental materials have certain features of contact with living tissues. They come into contact with both hard and soft tissues of the human body. Accordingly, the impact of emerging flows is more difficult to detect and investigate. The processes that occur during the interaction of implanted materials and adjacent areas of biotissues become more important.

The authors of the publications [5, 6] conducted experimental studies of some materials used in reconstructive and restorative surgery of facial bones and cements for fixing orthopedic structures during prosthetics. For some materials, significant differences in the EMF level were found. According to the results of the research, practical recommendations are proposed to limit the use of biomaterials with a significant difference in EMC. Taking into account the importance of the electromagnetic interaction of prosthetic constructions made of acrylic plastics with the tissues of the human body, the following studies were conducted.

Currently, for the manufacture of some fixed structures (crowns, bridge-like prostheses with plastic lining) and the bases of removable prostheses, many types of plastics are used, which are produced in different countries, in particular, Ukraine, Germany, the USA, the Czech Republic, Japan and others [7]. The following materials can be attributed to the most common in practice.

1. **"Ftorax"** – material for manufacturing the bases of removable prostheses produced by the company "Stoma" (Ukraine). It is a fluorine-containing acrylic copolymer. It is represented by two components (powder and liquid). The powder is a graft copolymer of methyl ether, methacrylic acid and fluororubber. The liquid is methacrylic acid methyl ether containing diphenylpropanedimethacrylic ether. "Ftorax" belongs to hot hardening plastics. The material accurately conveys the contours of the mucosa of the oral cavity, has high bending strength, optimal elasticity and is well polished, has sufficiently high cosmetic properties.

2**."Ethacryl-02"** - hot polymerization plastic also from the manufacturer "Stoma" (Ukraine), which in orthopedic dentistry is the option of choice for the manufacture of denture bases in the case of partial defects of the dentition or complete loss of teeth. Among the advantages, the inclusion of an oligomer in the composition of the liquid should be highlighted, which allows to reduce the content of residual monomer and prolong the life of the molding mass, and its high plasticity ensures accurate transfer of the shape of the prosthesis. Similar to "Ftorax", it has high cosmetic properties due to its translucency and the inclusion of "veins" in the composition of the material, imitating the appearance of the mucous membrane of the oral cavity.

3. **Colorless basic plastic** of the company "Stoma" (Ukraine) is a material that is used for the manufacture of the bases of complete removable prostheses in cases where plastic containing dyes is contraindicated for the patient. The powder is a polymethyl methacrylate suspension containing tivumin, which determines the stability of the color of the plastic and prevents its aging from the oxidative action of air. It is also a plastic of hot polymerization. In addition, it contains a component that prevents abrasion and thus provides this material with increased strength.

4. **"Vertex Implacryl"** of the company "DENTIMEX" (USA) is a super-strong plastic of hot polymerization, which is used for the manufacture of the bases of removable dental prostheses, in particular, partial, complete removable prostheses with support on implants. "Implacryl" is characterized by high impact viscosity, which is 50 % higher than that of ordinary base plastics, so this material is particularly resistant to destruction. "Vertex TM Implacryl" in combination with dyes for acrylic plastics "Acrylic Stain" allows to make not only reliable, but also aesthetic dental prostheses.

5. **"Vertex Basio 20"** (Netherlands) is a hot polymerization plastic used for the manufacture of removable denture bases: partial or complete.

6. **"Synma-M"** of the company "Stoma" (Ukraine) is also a plastic of hot polymerization, which is used in orthopedic dentistry for the manufacture of crowns and for lining fixed prostheses.

A detailed description of the electromagnetic properties of certain other medical materials and those materials which are in contact with the human body, is to be found in the authors' publications [8-10]. These publications outline the methods for engineering experiments conduction and preparation, measuring the parameters of biomaterials, their comparison, and determining their level of electromagnetic compatibility with the human body. The research is based on the method described in the authors' patent [11].

An emissive activity of certain materials was determined using a highly sensitive radiometric system, and the experimental results demonstrated the possibility of generating positive and negative microwave electromagnetic flows between a biotissue and the implant. A significant impact of positive and negative microwave flows on the human body and on specific types of cells (including cancer cells) was confirmed by laboratory and clinical studies [12].

Experimental part

A measurement of a low-intensity microwave radiation from the human body and implanted materials at a temperature of 36-37°C (i.e., 310 K) can be achieved with a radiometric system sensitivity of no less than 10^{-14} W [8,13]. This level of sensitivity ensures a strong detection and evaluation of electromagnetic fields and radiation from the studied physical and biological objects.

Modulation radiometers with heterodyne conversion of the input frequency are used in order to achieve such a sensitivity. The design of such a radiometer includes three stages of amplification: the input signal, the intermediate frequency signal, and the commutation frequency. The output signal of the modulation radiometer is to be represented by a simplified formula with two components — the power of the input signal and the power of the noise components [8]:

$$u_{RS} = K_{\Sigma} U_o^2 + K_{\Sigma} \Delta U_w^2 (f) \sum_{i=1}^{K} (\Omega - \Omega_i),$$

K_{Σ} – a total conversion coefficient of the radiometric channel;

$U_o^2, \Delta U_w^2$ – a variance (power) of the input signal and the noise components that have passed to the radiometer output.

The noise components' presence reduces the radiometer's sensitivity, when an additional filtering of these components at the output increases the measurement time.

The authors [14] propose a modulation radiometer scheme without a heterodyne conversion, which, by introducing a compensation block with a variable attenuator and a phase shifter, ensures compensation for fluctuating interference (see Fig. 2).

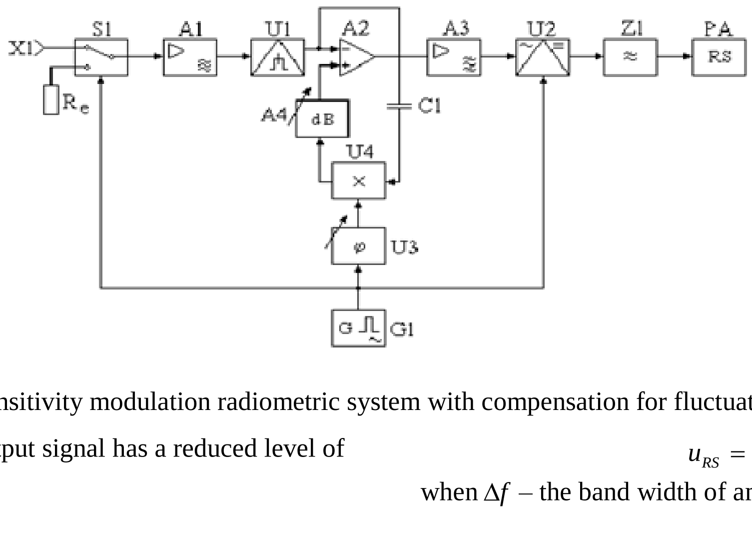

Fig. 2 High-sensitivity modulation radiometric system with compensation for fluctuating interference

As a result, the output signal has a reduced level of these interferences:

$$u_{RS} = K_{\Sigma} U_0^2 \Delta f ,$$

when Δf – the band width of amplifier A1.

A radiometer based on the proposed scheme, achieves sensitivity levels comparable to those of a heterodyne conversion scheme while significantly increasing the measurement speed. A detailed description of the working principle of the scheme and the complete signal conversion algorithms is provided in [14].

Description of the Experiment and the Results

Electromagnetic radiation parameters of acrylic plastics were measured at a frequency of 51 GHz using a highly sensitive radiometric system (RS).

Acrylic materials in the form of round washers with a diameter of 10 mm were placed in metal containers and placed for 30 minutes into a thermostat with a temperature equivalent to the human body temperature of 310 K.

After warming up, containers with material samples were placed under the receiving antenna of the radiometric system. The diameter of the metal round container is chosen to be slightly smaller than the aperture of the RS receiving antenna to receive the full signal of the material sample under study.

Before the study of the materials, RS calibration and measurement of the radiation level of two respondents were carried out. The average value of the electromagnetic radiation of two respondents was 2.53·10-13W. This value was used for comparison with the radiation level of the studied materials.

The results of emissivity of acrylic materials, coefficients of emissivity and percentage of coincidences are shown in Table 1.

Table 1 The results of measuring the emissivity of acrylics plastics

№	The research object	Power level P_M (10^{-13} W)	Coefficient β_M	% coincidence
1	**Human body (respondents)**	2,53	0.60	100
2	**Ftorax**	1,23	0,29	48,3
3	**Ethacryl-02**	0,95	0.22	36,6
4	**Colorless basic plastic**	1,49	0,35	58,3
5	**Vertex Implacryl**	1,52	0,36	58,3
6	**Vertex Basio 20**	0,89	0,21	35,0
7	**Synma-M**	1,35	0,32	53,3
8	**ABB**	4,2	1,0	>66

It should be noted that the total radiation level of the manufactured orthopedic constructions can be much higher and will be described by a more extended formula

$$P_{\Sigma} = \beta k T \Delta f_{RS} S_1 / S_2 ,$$

where, S_1 – the area of the dental prosthesis that is in contact with the biotissues of the human body; S_2 – the area of the studied (on RS) sample of acrylic plastic.

The obtained values of the RS indicator readings, which are presented in the table, were compared with the average value of the body radiation of two respondents.

The results of the research allow us to draw the following conclusions regarding the electromagnetic compatibility of the materials under study.

Conclusions

1. The studied samples of acrylic plastics all, without exception, form negative flows of electromagnetic radiation.

2. The highest level of electromagnetic compatibility (58.3 %) was found in the acrylic materials "Colorless Basic Plastic" (Ukraine) and "Vertex Implacryl" (Netherlands), as well as in domestically produced materials "Ftorax" and "Synma-M", which have some lower level of coincidence (48-53)%.

3. The lowest level of coincidence was recorded in samples of acrylic plastics "Ethacryl - 02" (36.6 %) and "Vertex Basio 20" (35.0 %).

4. The conducted research makes it possible to choose more acceptable materials for the manufacture of removable dental prostheses, as well as to determine the correlation between the emission of electromagnetic characteristics and the appearance of complications in patients during the operation of these structures.

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ДОСЛІДЖЕННЯ ЕЛЕКТРОМАГНІТНОЇ СУМІСНОСТІ МАТЕРІАЛІВ ДЛЯ СТОМАТОЛОГІЧНИХ ПРОТЕЗІВ

Стаття присвячена результатам дослідження електромагнітних властивостей групи стоматологічних матеріалів – акрилових пластмас, які широко використовуються в ортопедичній стоматології та ортодонтії. Вони є основним матеріалом для виготовлення різноманітних видів зубних протезів.

Для створення ортопедичного виробу проводять змішування порошку (полімера) та рідин (мономера), отримують суміш, з якої формують протез необхідної форми і розміру, після чого проводять затвердіння пластмаси. Отримані конструкції повинні відповідати визначеним вимогам, в тому числі і мало вивченій електромагнітній сумісності (ЕМС). Діелектричні матеріали при нагріванні формують власне електромагнітне випромінювання в міліметровому діапазоні, що є загальною властивістю нагрітих діелектриків. При цьому виникають електромагнітні потоки (ЕМП) різної направленості. Ці потоки можуть мати додатну або від'ємну спрямованість і, певним чином, впливати на прилеглі біотканини та організм людини в цілому. Тому авторами проведені дослідження електромагнітного випромінювання (ЕМВ) 6 матеріалів акрилових пластмас та визначені рівні їх ЕМС з біотканинами організму людини. Порівняно з рівнем випромінювання людини акрилові пластмаси і, відповідно, стоматологічні протези з них формують від'ємні потоки ЕМВ по відношенню до прилеглих біотканин. Найбільший рівень ЕМС (до 58 %) мають «Безколірна базисна пластмаса» та «Vertex Implacryl», дещо менший (48-53) % – пластмаси «Фторакс» та «Синма-М» і найменший рівень ЕМС (35-36) % зафіксовано у «Vertex Basio» та «Етакрил – 02». Проведені дослідження дозволяють вибрати більш прийнятні матеріали для виготовлення зубних тимчасових, постійних конструкцій та знімних повних і часткових протезів, а також визначати кореляційний зв'язок між впливом електромагнітних характеристик та появою ускладнень у пацієнтів в процесі експлуатації цих конструкцій.

Ключові слова: електромагнітне випромінювання, електромагнітна сумісність, акрилові пластмаси, зубні протези.

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