

FEATURES OF PHYSICAL AND MECHANICAL PARAMETERS OF ACRYLIC PLASTICS AFTER FULLERENE COATING

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ABSTRACT

The aim of the research is to study the physical and mechanical parameters of the bases in removable laminar dentures after modification of their surface.

Materials and methods: the studied samples were divided into two groups (group I – acrylic plastics, and group II – acrylic plastics with fullerene C_{60} nanocoating), 50 samples in each group. The coefficients of water absorption, water solubility, microhardness and deformation characteristics of materials were studied.

Results and conclusions: The material covered with fullerene C_{60} has a lower coefficient of water absorption and water solubility, which amounted to 0.55% and 0.23% respectively, from the initial weight of samples, as compared with acrylic plastics without coating (0.71% and 0.34%, respectively). The strength parameters of samples of group II were higher by 13.5% as compared to group I. The given results of water absorption and water-solubility show that acrylic plastics with fullerene C_{60} molecules coating has a lower coefficient of water absorption and water solubility, in comparison with acrylic plastics without coating. This indicates a higher degree of resistance to biodegradation of the modified surface material, in turn reducing the washing-out of residual monomer from the denture, which directly improves the strength parameters of the acrylic plastics and can prevent the development of denture stomatitis.

KEY WORDS: acrylic plastics, water absorption, water solubility, nanocoating with fullerene C_{60}

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INTRODUCTION

The quality prosthetics with partial and complete removable laminar dentures is an important issue in the clinical practice of orthopedic dentistry. According to various authors, the need for such types of structures varies from 50 to 75% of the total number of orthopedic patients [1,2,3].

Currently, the main materials used for manufacturing removable dentures are derivatives of acrylic and methacrylic plastics: from 91 to 98% of removable dentures are made of acrylic plastics [4,5,6].

The extensive period of using acrylic plastics in orthopedic dentistry as the main material for manufacturing various types of dentures since the 1930s and up to this day indicates its satisfactory biological, physical and mechanical properties. It meets the requirements of everyday dentistry because of its relatively good biocompatibility, chemical inertness, favorable mechanical properties, stable dimensions, aesthetic, technological benefits, the possibility to fix it, as well as its low cost [7,8,9].

However, among the list of positive qualities of acrylic plastics, there are certain shortcomings. This is supported by the fact that more than 26% of patients cannot use removable dentures, and 37% are forced to adjust to poorly-designed dentures [2,10].

The disadvantages of acrylic prosthesis include inaccurate correspondence of the prosthetic base of the relief of the tissues of the prosthetic bed, inadequate pressure, insufficient mechanical strength, the presence of residual

monomer, disruption of thermoregulation, microbiological imbalance and biodegradation [11,12,13,14].

In order to improve the strength parameters and reduce the degree of water absorption of plastics, we developed a new way of enhancing the removable laminar denture, manufactured according to traditional technology using the nanosized material – molecules of fullerene C_{60} .

THE AIM

The aim of the research is to study the physical and mechanical parameters of the bases in removable laminar dentures after the modification of their surface

MATERIALS AND METHODS

We used the following samples of materials: acrylic plastics; and acrylic plastics, coated with a layer of fullerene C_{60} nanomaterial.

The study of certain physical and mechanical properties was conducted in accordance with the general requirements of GOST 143559-79, as well as GOSTs for testing each indicator on carefully selected samples without cracks, pores and other defects.

Samples of acrylic plastics, and acrylic plastics with fullerene C_{60} nanocoating were obtained using the following technological methods:

1. Polymerization of acrylic plastics by the compression method of forming plastic paste in the cuvette.

2. Coverage of polymerized acrylic plastics with molecules of fullerene C_{60} , by the method of magnetron sputtering of materials.

Measurement of the thickness of samples was conducted using the micrometer with accuracy up to 0.001 mm.

According to the materials and methods of manufacturing, the samples were divided into two groups of 50 samples in each:

Group I – samples made of acrylic plastics

Group II – samples made of acrylic plastics with fullerene C_{60} nanocoating.

DETERMINING THE COEFFICIENTS OF WATER ABSORPTION AND WATER SOLUBILITY

Before testing, the samples were conditioned according to GOST 12423-66 for at least 16 hours (at the temperature of $23 \pm 2^\circ \text{C}$ and relative humidity of $50 \pm 5\%$). The length, width and thickness of the samples were measured using micrometer MK 0-25 GOST 6507-78 with accuracy of ± 0.01 mm in at least three places.

To determine water absorption and water solubility, the samples were immersed in distilled water for 30 days at the temperature of $37 \pm 1^\circ \text{C}$ in a dry air thermostat, so that the samples did not touch the walls of the Petri glass cup, each other and the surface of water. The initial mass (m_0) of samples was determined by weighing them on scales of class II with an error of not more than 0.2 mg. At the end of this period, samples were removed and gently wiped with dry filter paper. After 1 min after removing samples from water, they were weighed with the same precision as in the beginning, determining the mass m_1 . After weighing, the samples were again conditioned to the constant mass in the exicator, as described above. The constant mass was recorded as m_2 . Water absorption (W_a , in $\mu\text{g} / \text{mm}^3$) was calculated by the formula: $W_a = \frac{m_0 - m_1}{V}$, where m_0 is the initial mass of the sample, m_1 is the sample mass after exposure in water for 30 days, V is the volume of the sample. Water solubility (W_{sl} , in $\mu\text{g} / \text{mm}^3$) was calculated by the formula: $W_{sl} = \frac{m_0 - m_2}{V}$, where m_0 is the initial mass of the sample, m_2 is the sample mass after exposure in water for 30 days and drying, V is the volume of the sample.

For the study of microhardness (in mPa), samples of the studied materials were additionally grinded and polished to a mirror luster.

Microhardness of the examined samples was studied according to the Vickers method with the microtrometer PMT-3, by the size of the imprint of the diamond pyramid (indenter) at different loads.

The sample was placed on the microscope stage, whose rotation led the sample to the diamond pyramid, lowering it to the sample, which was examined so that the distance between the center of the imprint and the edge of the sample was not less than 2-2.5 mm. The load time was 10 seconds. Measurements of microhardness were carried out at three points of each sample. After the sample was released from the load, the microscope stage was brought to the microscope's eyepiece. The imprint was measured

with the accuracy up to $0.3 \mu\text{m}$.

The value of microhardness by Vickers (Hv, mPa) was determined by the formula:

$$Hv = \frac{18540P}{2a^2}$$

where P is load, g;

2a is arithmetic average of the diagonals length, μm .

For each of the studied samples, we obtained three imprints and found the average value.

The deformation characteristics of all groups of studied samples were examined in their deformation in terms of compression and tension. The study of deformation characteristics of the examined samples in terms of compression was conducted using the deformation machine MRK-1. To determine the compression deformation, samples of materials were cylinders of $4 \times 4 \times 10$ mm. The deformation rate was $0.1 \text{ mm} / \text{min}$.

The value of the resilience boundary was determined by the formula:

$$\sigma_{rs} = \frac{P_0}{S_0}$$

where P_0 is the load at which the first deviation from the linearity on the deformation curve (H) is observed;

S_0 is the initial plane of the cross-sectional sample (m^2).

Tension deformation was conducted in the discontinuous facility MRK-1 with the deformation rate of $0.2 \text{ mm} / \text{min}$ on the dumbbell shaped samples with the dimensions of the working part of $14 \times 10 \times 3$ mm. The samples were fastened to the clamp of the test machine in such a way that the larger axis of the sample coincided with the loading axle. The tightening of the clamps did not allow the sample to slip during the test.

According to the obtained deformation curves, we determined the yielding boundary ($\sigma_{0.2}$), the strength boundary (σ_{st}) and the maximum deformation to destruction Σ_{max} .

To determine the strength boundary, in the formula P_0 was substituted with P_{max} – the load at which the sample is destroyed.

The study of bending deformation characteristics was also carried out in the MRK-1 facility with an aperture for four-point bending. To this end, samples of materials $35 \times 5 \times 3$ mm from different groups were used.

To determine the reliability of the research results, the variational-statistical analysis was used for interrelated observations, calculating the reliability of difference according to Student. Statistical processing was conducted using the STATISTICA 6.0 (StatSoft, USA) software with a mean (M) and a standard error (m). Differences between the groups were considered statistically significant at $p < 0.05$.

RESULTS

Indicators of water absorption and water solubility are presented in Table I.

Based on the data presented in Table I, the average initial mass of samples of acrylic plastics material was $348.8 \pm 10.3 \text{ mg}$. After

Table I. Average values of main characteristics of sample materials acrylic plastics and acrylic plastics with fullerene C₆₀ molecules coating and indicators of water absorption and water solubility on the 30th day of the experiment

No	Title of the material	a, mm	b, mm	h, mm	V, mm ³	m ₀ , mg	m ₁ , mg	m ₂ , mg	W _a , μg/mm ³	W _{st} , μg/mm ³
1	Acrylic plastics	6.1 ±0.05	3.5 ±0.02	14.7 ±0.5	315 ±9.26	348.8 ±10.3	351.3 ±10.4	347.6 ±10.3	7.80 ±0.27	3.87 ±0.18
2	Acrylic plastics with nanocoating	6.24 ±0.07 p>0.05	3.47 ±0.01 p>0.05	16.1 ±0.26 p<0.05	348.5 ±3.86 p<0.05	382.1 ±6.2 p<0.05	384.2 ±6.3 p<0.05	381.2 ±6.1 p<0.05	5.90 ±0.30 p<0.05	2.57 ±0.28 p<0.05

Table II. Average values of microhardness indicators in the presented materials (M ± m, n = 10)

Title of the material	H _v , Mpa
Acrylic plastics	307.3±6.5
Acrylic plastics with nanocoating	701.8±13.1 p<0.05

Table III. Average values of strength and plasticity of samples made of the examined materials in the tension study (M ± m, n = 10)

Title of the material	Young's modulus, E, MPa	σ _{rs} , MPa	σ ₀₂ , MPa	σ _{st} , MPa	δ, %
Acrylic plastics	241.78±0.55	36.02±1.01	37.25±1.35	40.25±1.06	0.38±0.038
Acrylic plastics with nanocoating	356.15±9.39 p<0.05	36.54±1.30 p>0.05	38.40±1.47 p>0.05	53.16±1.59 p<0.05	3.20±0.41 p<0.05

Table IV. Average values of the strength and plasticity of samples made of the examined materials in the compression study (M ± m, n = 10)

Title of the material	Young's modulus, E, MPa	σ _{rs} , MPa	σ ₀₂ , MPa	σ _{st} , MPa
Acrylic plastics	939.72±9.09	59.96±2.42	62.76±2.38	95.32±1.9
Acrylic plastics with nanocoating	952.44±12.32 p>0.05	64.67±2.01 p>0.05	67.18±2.06 p>0.05	89.70±1.74 p<0.05

Table V. Average values of strength and plasticity of samples made of the examined materials in the bending study (M ± m, n = 10)

Title of the material	Young's modulus, E, MPa	σ _{rs} , MPa	σ _{st} , MPa	w _{max} , mm
Acrylic plastics	635.8±13.71	48.8±0.83	72.5±1.77	5.08±0.05
Acrylic plastics with nanocoating	1135.4±11.33 p<0.05	56.4±0.6 p<0.05	105.3±0.89 p<0.05	4.99±0.1 p>0.05

30 days of exposure in distilled water at 37°±1°C, the average sample mass increased to 351.3±10.4 mg, and after conditioning the samples to constant mass in the exicator, their average mass decreased to 347.6 ± 10.3 mg. Accordingly, the coefficient of water absorption on the 30th day was 7.80 ± 0.27 μg / mm³, and the coefficient of water solubility was 3.87 ± 0.18 μg / mm³.

The average initial mass of samples of acrylic plastics material with fullerene C₆₀ molecules nanocoating was 382.1 ± 6.2 mg. After 30 days of exposure in distilled water at 37°±1°C, the average sample mass increased to 384.2 ± 6.3 mg, and after conditioning the samples to constant mass in the exicator, their average mass decreased to 381.2 ± 6.2 mg. Accordingly, the coefficient of water absorption on the 30th day was 5.90 ± 0.30 μg / mm³, and the coefficient of water solubility was 2.57 ± 0.28 μg / mm³.

The obtained data show that the material covered with fullerene C₆₀ has a lower coefficient of water absorption

and water solubility, which amounted to 0.55% and 0.23%, respectively, than the initial weight of samples, as compared with acrylic plastics without coating – 0.71% and 0.34%, respectively.

The study of microhardness allows us to evaluate the properties of thin surface layers of dental base materials, that is, their ability to resist local plastic deformation, which arises under the influence of the action of more solid materials.

As our studies have shown (Table II), the microhardness indicators of base material samples are significantly higher in Group II, as compared with Group I. The average value of microhardness is 307.3 ± 13.3 mPa, in the second group – 701.8 ± 26.6, which is by 2.28 times higher than in the second group.

In the study of tension deformation of the materials, it was determined that samples of basic materials are de-

stroyed when stretching after plastic deformation within the range of 0.38-3.20%, which makes it possible to determine the strength of the materials under examination. It should be noted that samples of acrylic plastics are destroyed at plastic deformation of 0.38%, and samples of acrylic plastics with nanocoating at plastic deformation of 3.20% (Table III).

From the data given in the table it is established that the type of material significantly influences the strength value of the base material samples: acrylic plastics and with nanocoating. The plastic deformation is somewhat higher in the sample with nanocoating.

As shown by the conducted studies, compression deformation characteristics, for each of ten samples of basic materials, and with fullerene C_{60} nanocoating, differences in strength and compression deformation were not significant (Table IV).

The result of the bending study is the arithmetic mean of the values in the destructive stress on the bend of the experimental samples from each group. We found that the magnitude of the force, applied to the samples in the second group, leading to deformation, is by 13.5% higher than in the first group (Table V).

DISCUSSION

As a result of the combined effect of the prosthesis on the tissues of the prosthetic bed, complications may arise when used, such as denture stomatitis [4,15]. The percentage of symptoms of denture stomatitis in patients using removable laminar dentures varies according to various authors within 15-70% [16,17].

One of the main causes of denture stomatitis is the presence of a residual monomer in the prosthesis. The residual monomer is the amount of monomer that is not connected to the polymer during the polymerization process. Incomplete polymerization of acrylates reduces the physical, mechanical and biological properties of dentures. The monomer can be washed into saliva and cause cytotoxic effects in the oral cavity. The higher the number of monomers that have not reacted, the higher will be the harmful effect [18,19,20].

In case of disrupted polymerization regime, the prosthetic base may contain from 3.4 to 8% free monomer, which is released from the denture for 5 years. But even in case of correct mode and advanced polymerization techniques, up to 0.5% of residual monomer remains in the plastic [15,21].

There are two indicators that affect the amount and rate of leaching of the residual monomer in the oral cavity: water absorption – the ability of the material to saturate and retain water over time and water solubility – the number of components of the material that is washed away and replaced by water molecules [22].

The main component of saliva is water, which is one of the main factors of biodestruction of acrylic dentures. Water molecules can easily penetrate into the polymeric network, which allows the removal of unbound monomer or other components of the plastics. It takes from one to

two months after the start of using a denture to saturate polymer with water. The mouth fluid, as physiologically active, provokes the release of toxic substances from the denture polymeric bases more than the neutral extractant – distilled water [23].

The excess content of residual monomer and the degree of water absorption affect the strength parameters of denture. The strength of denture decreases with excessive content of residual monomer, resulting in its deformation under load. In addition, monomer is washed primarily from the surface of the prosthetic base, and thus the structure of the polymer dissolves, creating tension that ultimately leads to decreased strength. In orthopedic structures, this tension over time causes cracking and breakage of the bases of dentures [24].

Fractures of dentures reach 15% in the first year of use. Breakdowns of plastic bases make up 35-49% of the total number of manufactured removable laminar dentures. Duration of using the removable laminar dentures until the first break is on average 0.5-1.4 years [10,25].

Since currently there is no material that could replace acrylic plastics, an important task is to improve its biological, physical and mechanical properties. Thus, it is possible to increase the parameters of strength and reduce water absorption of plastic by means of a new way of improving the removable laminar dentures, produced according to the traditional technology, with nanosized material – molecules of fullerene C_{60} .

CONCLUSIONS

1. The given results of water absorption and water solubility show that acrylic plastics with fullerene C_{60} nanocoating has a lower coefficient of water absorption and water solubility, as compared to acrylic plastics without coating. This indicates a higher degree of resistance to biodegradation of the modified surface material, in turn reducing the washing-out of residual monomer from the denture, which directly improves the strength parameters of the acrylic plastics.
2. The obtained data prove that nanocoated plastics have higher physical-mechanical characteristics as compared to conventional plastics. The microhardness index is by 2.28 times higher in modified plastics, indicating a better surface ability to withstand mechanical stresses directed on the surface, without changing the surface structure.
3. Samples with nanocoating are more resistant to destruction because the index of relative residual deformation prior to the sample destruction is by 2.82% higher than in conventional plastics. Therefore, it can be argued that such material can be used in dentistry to reduce the number of breakages of removable dentures and prolong their lifetime.

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The Authors declare no conflict of interest.

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