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COMPARATIVE ANALYSIS OF BIOCOMPATIBILITY CHARACTERISTICS OF BASE RESINS FOR REMOVABLE DENTURES

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We manufactured and studied samples of acrylic plastics Villacryl, Ftorax and elastic thermoplastic Acron. The relief of the surfaces of the samples was studied at different scale levels using digital optical microscopy (Carl Zess NU-2E optical microscope), micro-profilometry (Veeco DEKTAK 3030 profilometer) and atomic force microscopy (scanning probe microscope Bruker NanoScope IIIa Dimension 3000 TM). The wettability of surfaces at the macro level was characterized by measuring the wetting angle of a stationary drop. Samples of the elastic plastic Akron demonstrate the smallest wetting angle (WA) – 60.8°, which indicates good wettability, but have the highest surface roughness (14 nm). Acrylic plastics Villakryl and Ftorax, despite a smoother surface (8 and 10 nm), have a higher WA (65.1° and 83°), which indicates lower hydrophilicity due to the chemical composition of the surface. Elastic prosthetic plastics with their unique surface interaction profiles hold promise for specialized applications in partial removable dentures.

Key words: absence of teeth, acrylic resin, elastic resin, biocompatibility, wetting angle, partial removable dentures.

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ХАРАКТЕРИСТИК БІОСУМІСНОСТІ БАЗИСНИХ ПЛАСТМАС ДЛЯ ЗНІМНИХ ЗУБНИХ ПРОТЕЗІВ

Нами виготовлено і досліджено зразки акрилових пластмас Villacryl, Фторакс і еластичної термопластичної пластмаси Acron. Рельєф поверхонь зразків досліджувався на різних масштабних рівнях за допомогою цифрової оптичної мікроскопії (оптичний мікроскоп Carl Zess NU-2E), мікро-профілометрії (профілометр Veeco DEKTAK 3030) та атомно силової мікроскопії (сканувальний зондовий мікроскоп Bruker NanoScope IIIa Dimension 3000 TM). Змочуваність поверхонь на макрорівні характеризувалась методом вимірювання крайового кута змочування стаціонарної краплі. Зразки еластичної пластмаси Acron демонструють найнижчий кут змочування (КЗ) — 60,8°, що вказує на хорошу змочуваність, але має найвищу шорсткість поверхні (14 нм). Акрилові пластмаси Віллакрил та Фторакс незважаючи на гладшу поверхню (8 і 10 нм), мають вищий КЗ (65,1° і 83°), що вказує на меншу гідрофільність через хімічний склад поверхні. Еластичні пластмаси для знімних протезів з їхніми унікальними профілями взаємодії поверхні є перспективними для застосувань у часткових знімних протезах.

Ключові слова: відсутність зубів, акрилові пластмаси, еластичні пластмаси, біосумісність, кут змочування, часткові знімні протези.

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Modern materials for the fabrication of both fixed esthetic and removable dentures are widely used in contemporary dentistry. For patients with free-end edentulous spaces or medium to large defects of the dental arches, removable partial dentures (RPDs) are commonly used. Among the materials used for fabricating RPDs, acrylic resins and thermoplastics are most prevalent [1]. Acrylic partial dentures, although possessing well-polished, smooth surfaces, are more allergenic and toxic due to the presence of residual monomer (methyl methacrylate). Elastic dentures are made from thermoplastic resins, which are more porous and less hygienic, but bioinert, non-allergenic, and non-toxic [2, 3].

Studying the surfaces of structural materials at the micro- and nanoscale is gaining importance in dental research, as it allows exploration of complex interactions between dental materials and the oral environment and reveals the factors that determine the biocompatibility of removable prosthesis materials. Atomic force microscopy (AFM) has demonstrated how micro- and nanoscale surface features strongly influence bacterial adhesion and biofilm formation. In particular, surface roughness at various scales may either promote or hinder cell attachment and growth, affecting tissue integration as well as pathogenic colonization. Additionally, AFM-based force spectroscopy enables quantitative analysis of adhesion forces between dental material surfaces and biological entities such as proteins, bacteria, and cells, and allows the study of nanomechanical properties, including wear resistance and material degradation [4, 5, 6, 8].

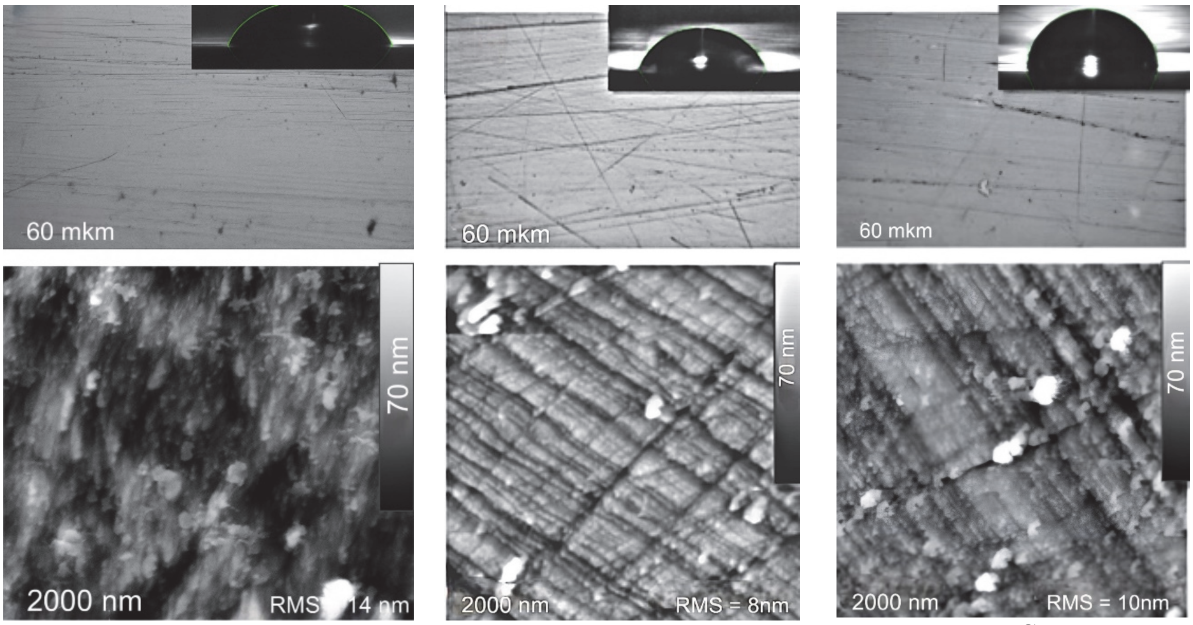
Surface wettability analysis, especially wetting angle (WA) measurements, complements AFM data by characterizing surface energy and hydrophobicity, both critical factors in protein adsorption, cell adhesion, and oral fluid interaction with teeth and denture surfaces. Tański T., Ziębowicz B. et al. [13] provided a comprehensive review of AFM applications in biomaterials research, highlighting its ability to measure topography, mechanical properties, and molecular interactions in various environments, and how these properties influence biocompatibility and functionality of prosthetic materials. Sumbul F, Rico F. [12] employed AFM-based spectroscopy to analyze protein, cell, and bacterial adhesion. Tathagata Nandi, Sri Rama Koti Ainavarapu [14] conducted research on mechanical properties of biomaterials using AFM, including strength, elasticity, and adhesive properties of prosthetic materials.

Sachelarie L., Drăgan E., Albert C. et al. [11] explored new approaches for evaluating biocompatibility and its impact on prosthesis success. Bacterial colonization on dental materials was studied by Yu Yang et al. [15], showing how bacterial filamentation influences colonization of heterogeneous surfaces, with implications for implants and orthodontic devices. Wettability across different scales was examined by Dan Daniel et al. [7]. Misiura A. et al. [9] investigated how nanometer-scale surface roughness affects contact angle hysteresis and protein adsorption, demonstrating that nanoscale features significantly influence surface properties and biocompatibility. They researched mechanisms of cell adhesion as a foundation of biocompatibility, showing that adhesion is determined by the dynamics of the protein layer on the material surface.

The purpose of the study was to experimentally substantiate the properties of dental materials for removable dentures by analyzing their biocompatibility and nanostructure using atomic force microscopy.

Materials and methods. We fabricated and examined samples of Villacryl (Zhermapol, Poland) and Ftorax (Stoma, Ukraine), acrylic resins, and one elastic thermoplastic resin. Five samples of each base resin were prepared, sized 10×10 mm. Surface topography was studied at different scales using digital optical microscopy (Carl Zess NU-2E), microprofilometry (Veeco DEKTAK 3030), and AFM (Bruker NanoScope IIIa Dimension 3000 TM). Macroscale wettability was characterized via wetting angle (WA) measurements of static drops, using a digital microcamera and ImageJ software. Nanolevel adhesive properties were analyzed through AFM force spectroscopy, evaluating the interaction forces between silicon nitride nanoprobes and sample surfaces [10]. A key characteristic of the retraction curve for bioadhesion studies is the pull-off force, which reflects maximum adhesion between the probe tip and the sample surface. All measurements were performed at room temperature, which is directly relevant to clinical effectiveness.

Results of the study and their discussion. The balance of adhesive and cohesive forces among liquid, solid surface, and surrounding air can be described by the contact angle. This is the angle between the surface plane and the tangent at the edge of a liquid droplet in equilibrium, at the three-phase contact point (Fig. 1).



A B C

Fig. 1. Optical micrographs of plastic sample surfaces: Elastic resin (A), Villacryl (B), and Ftorax (C). Corresponding AFM images of nanoscale surface topography between micro-scratches are shown below. Insets depict equilibrium droplet shapes of distilled water on each surface.

WA is a critical parameter for dental materials as it affects interaction with saliva, blood, and other biological fluids in the oral cavity. A material with a high WA (hydrophobic) shows poor wettability and may not support optimal protein or cell adhesion. Conversely, materials with low WA (hydrophilic) provide better wettability and promote adhesion.

CA also plays a major role in bacterial adhesion and biofilm formation. Biofilms colonies of microorganisms attached to surfaces – can lead to infections and complications. Hydrophobic materials with high CA are more susceptible to biofilm formation than hydrophilic ones.

Elastic resin samples demonstrated the lowest CA (60.8°), indicating good wettability despite the highest surface roughness (14 nm). This highlights the dominant role of surface chemistry in wettability. The Villacryl resin, with the smoothest surface (8 nm), exhibited a higher CA (65.1°), suggesting lower hydrophilicity due to its chemical composition. Ftorax showed the highest CA (83°), indicating the least wettability. Its intermediate roughness (10 nm) and presence of fluorinated compounds likely contribute to its hydrophobicity. The observed CA differences among the resins, despite similar roughness (8–14 nm), underscore the critical role of surface chemistry. The CA range (61°–83°) reflects significant differences in surface energy and composition.

Material biocompatibility is closely linked to surface energy and wettability. Materials with moderate wettability balancing hydrophobic and hydrophilic traits – support optimal protein adsorption and cell adhesion. Highly hydrophobic surfaces may cause protein denaturation, while overly hydrophilic surfaces may not sustain sufficient interaction for stable protein adsorption, thus potentially reducing biocompatibility. Therefore, understanding and controlling surface energy and wettability is crucial in designing biomaterials for applications in dentistry and implantology.

From Table 1, it is evident that surface roughness on the micro- and nanoscales has secondary importance in influencing wettability and adhesive properties compared to chemical bonding and electrostatic interactions.

Table 1

Surface roughness (RMS), wetting angle, and atomic force spectroscopy results of investigated dental materials

Material	RMS, nm	Wetting Angle, °	Pull-off Force, nN	Separation Distance, nm	Capillary Force, nN	Adhesion Work, J/m²
Elastic Acron	14	60.8	36	89	8.93	0.22
Villacryl	8	65.1	48	182	7.71	0.32
Ftorax	10	83	57	225	2.23	0.44

For the elastic resin, these distances are comparatively small, indicating predominance of chemical interactions on the surface, resulting in lower adhesion work values.

Based on wettability and adhesion measurements at macro- and nanoscale, a prognostic interpretation of their suitability for removable denture applications can be made. The Acron elastic resin, showing the smallest separation distances and lowest adhesion work, offers favorable properties and unique advantages for dental use, especially in removable prosthetics.

Elastic resin Acron, with its low adhesion, may be especially suited for temporary or partial dentures, where ease of cleaning and reduced plaque accumulation are priorities.

Thus, AFM provides valuable insights complementing macroscale WA and roughness measurements, enabling detailed understanding of nanoscale surface properties such as elasticity, plasticity, and bonding strength – critical for evaluating material behavior in biological environments and predicting biocompatibility [4, 7, 10].

A number of authors have indicated that, in order to improve the effectiveness and biocompatibility of dental implants, surface modifications and osteointegration analysis have been studied. The advantages of using hydroxyapatite coatings on dental implants have been proven, particularly in enhancing osteointegration and reducing the healing period [5, 6, 8].

We conducted a series of AFM force spectroscopy measurements across different sample surface areas, collecting force–distance curves at 1 μm intervals. By comparing nanoscale parameters such as capillary forces, adhesion work, and interaction range with macroscale CA and roughness data, we obtain a comprehensive, multiscale assessment of surface properties. This informs material potential for tissue integration and inflammation resistance.

Additionally, we studied the biocompatibility of modern materials used for esthetic fixed dental prostheses for comparison. Our findings complement existing scientific data on the biocompatibility of materials used for metal-free esthetic fixed prostheses [8, 15]. Also we studied zirconium dioxide, metal ceramics and press ceramics biocompatibility. The contact angle for zirconium dioxide is 86.5 units and for press ceramics is 40.7 units. The use of dentures based on zirconium dioxide and press ceramics helps to reduce the development of inflammatory processes in the the marginal periodontium, due to lower cell adhesion.

The wettability properties of dental materials were investigated, and the characteristics of their surface properties were presented. The significant role of atomic force microscopy (AFM) in studying material surfaces and assessing the biocompatibility of dental materials based on their surface wettability was highlighted [7, 11, 13].

Conclusion

Elastic resin samples exhibited the lowest CA (60.8°), indicating good wettability, despite the highest roughness (14 nm). Acrylic resins Villacryl and Ftorax, with smoother surfaces (8 and 10 nm), showed higher CA values (65.1° and 83°), indicating lower hydrophilicity due to surface chemistry. This confirms that chemical composition dominates roughness in determining wettability.

Elastic resins for removable dentures, due to their unique surface interaction profiles, are promising for specialized applications such as partial removable dentures. Their potential to reduce biofilm formation, ease maintenance, and enable surface customization makes them valuable in clinical removable prosthodontics.

Prospects for further research. However, base resin application should be carefully considered in context of specific clinical needs, and further in vivo research is required to fully assess their effectiveness in the complex oral environment. Combining these materials with surface modifications may offer a path to optimizing properties for removable prosthetic use.

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