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TRIBOLOGICAL TESTS OF ACRYLIC TEETH FOR REMOVABLE DENTURES

BADANIA TRIBOLOGICZNE ZĘBÓW AKRYLOWYCH DO PROTEZ RUCHOMYCH

Key words: dentistry, dentures, acrylic teeth, structure, wear.

Abstract: The functionality of removable dentures is ensured by proper diagnostics and clinical modeling. No less important are the structural conditions and the biotribological and biomechanical context, which determine the wear resistance in the contact of opposing teeth and the contact of the denture plate with the stomatognathic system. The aim of the study is to evaluate acrylic teeth used in prosthetic reconstructions based on microstructural, micromechanical and tribological tests. Samples for testing were taken from teeth for removable dentures made by various manufacturers. Microstructural analyses were performed using an optical microscope and a scanning microscope. Microhardness and elasticity coefficient measurements were performed on the NHT device. Tribological tests were performed on a Roxana Machine Works tester using a friction node: ball – 3 discs made of the tested material. The conducted research allowed for the evaluation of the structural quality of acrylic teeth and the determination of the tribological interaction resulting from the contact of synthetic and natural teeth in the presence of artificial saliva.

Słowa kluczowe: stomatologia, protezy, zęby akrylowe, struktura, zużycie.

Streszczeni: Funkcjonalność protez ruchomych zapewnia prawidłowa diagnostyka i modelowanie kliniczne. Nie mniej ważne są uwarunkowania strukturalne oraz kontekst biotribologiczny i biomechaniczny, które decydują o odporności na zużycie w kontakcie zębów przeciwstawnych oraz o kontakcie płyty protezy z układem stomatognatycznym. Celem opracowania jest ocena zębów akrylowych stosowanych w rekonstrukcjach protetycznych na podstawie badań mikrostrukturalnych, mikromechanicznych i tribologicznych. Próbki do badań pobierano z zębów do protez ruchomych wykonanych przez różnych producentów. Analizy mikrostrukturalne wykonano na mikroskopie optycznym i mikroskopie skaningowym. Pomiary mikrotwardości i współczynnika elastyczności przeprowadzono na urządzeniu NHT. Badania tribologiczne wykonano na maszynie Roksana Machine Works z zastosowaniem węzła tarcia: kula – 3 krążki z materiału badanego. Przeprowadzone badania pozwoliły na ocenę jakości strukturalnej zębów akrylowych oraz na wyznaczenie interakcji tribologicznej wynikającej z kontaktu zębów syntetycznych i naturalnych w obecności sztucznej śliny.

INTRODUCTION

The properties of oral restorations must be such that the structures can handle the loads associated with chewing. However, the features and parameters of these restorations must be considered in a comprehensive way. It is important to know that the impact of dental materials on the stomatognathic system (SS) depends on interrelated physical, chemical, optical, mechanical, thermal, electrical,

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and biological properties **[L. 1–9]**. Biomaterials that replace the perfect structure of natural teeth are three standard biomaterials – ceramics, composites, and acrylic polymers. These materials have very different properties from each other **[L. 10–17]**. The doctor decides on the type of artificial teeth to be used for an individual patient, because certain properties may be considered favorable or unfavorable in a specific application.

The aim of the study is to evaluate acrylic teeth used in prosthetic reconstructions based on microstructural, micromechanical, and tribological tests.

The teeth for dentures are made of modified and unmodified acrylic materials. Different pigments are used to obtain different shades of teeth, and a cross-linking agent is introduced to improve strength **[L. 3, 18, 19]**. Work is underway to improve the tribological properties of acrylic teeth, including the resistance to wear in sliding contact **[L. 3, 9, 10, 12, 15, 20–24]**.

The structural and tribological analysis of teeth for dentures available for clinical applications is justified in the scientific and application aspects.

MATERIALS AND METHODS

Polymer teeth for dentures were selected for microstructural, micromechanical, and tribological tests:

- Gnathostar (Ivoclar Vivadent),
- Postaris DCL (Ivoclar Vivadent),
- Major Super Lux (Major),
- Dentex – V (Dentex),
- Mifam Super Lux (SpofaDental),
- Classic Plus (Formed),

Microstructural tests were performed on the chewing surfaces of the teeth.

Micromechanical tests were performed after cutting with a circular saw in the axial sections. Sections were made along the long axis of the teeth, perpendicular to the maxillary and mandibular dental arches, and horizontal sections perpendicular to the long axis of the teeth.

For tribological tests, samples were made in the shape of ϕ1/4”discs with a thickness of 1/16”. The material was taken from polymer teeth by cutting them; 15 pieces of each material (**Fig. 1**).

After cutting, the samples were embedded in resin and polished using a Struers TegraForce-5 device, where the surface layer required for the test was achieved using programmed operations.

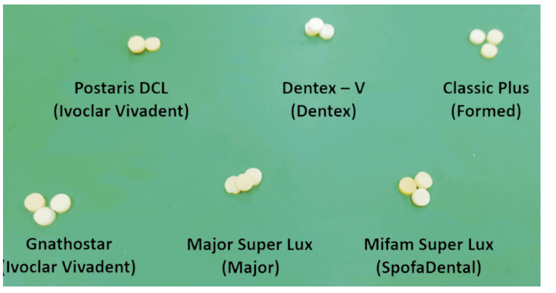

Fig. 1. Discs for tribological tests obtained from the crown of teeth from the chewing zone, in horizontal sections to the long axis

Rys. 1. Krążki do badań tribologicznych uzyskane z korony zębów ze strefy żującej w przekrojach horyzontalnych do osi długiej

Microstructural analyses of the chewing surfaces were performed on a Hitachi S3400N scanning electron microscope, and microstructural analyses in sections were performed on a Zeiss Stemi 508 optical microscope.

Micromechanical properties tests, including microhardness and Young’s modulus measurements in selected sections, were carried out on an NHT^3 device by Anton Paar. They were determined by using a Berkovich indenter. In the measurements, the values of force and depth of penetration of the blade were continuously recorded during the loading and unloading cycle. The maximum load value was 200 mN, the loading and unloading speed was 400 mN/min, and the maintenance time of the maximum load was 5 s. For each cycle, the indenter load was determined as a function of the depth of penetration. The analysis of micromechanical properties was based on the Oliver and Pharr method, according to which the microhardness (HV) and elastic modulus of the tested material (E) were calculated from the indentation curve in accordance with the applicable standard **[L. 25]**. The micromechanical parameters of teeth from different manufacturers were determined as the average of 10 measurements in the sections selected for testing.

Tribological tests were performed on a Roxana Machine Works tester, using a friction node: ball – three disc made of the tested material. Counter-samples were standard Sø 1/2” ceramic balls made of zirconium oxide, made with a deviation of 0.00013 mm according to ASTM F2094-02a. Before testing, the discs and counter-samples were moistened for 48 hours in Kserostemin artificial saliva by Aflofarm. To model the physiology of chewing contact, the Kserostemin preparation was sprayed into the test cup (**Fig. 2**). The sliding friction took place in the presence of artificial saliva under comparable conditions. The geometry of the sliding test node approximated the spatial arrangement found in SS (**Fig. 2**) **[L. 9]**. It allowed imitation of the change in wear intensity observed in in vivo studies, which is associated with a change in contact surface area. The tests were carried out with the following parameters:

- rotational speed: 200 rpm ± 5 rpm,
- operating temperature: 36.6°C ± 1°C,
- load: 100 N ± 3N,
- duration: 15 min ± 5 s.

The measure of the anti-wear properties of the tested materials was the average diameters of the wear defect. During the test, the friction torque was continuously recorded, and the coefficients of friction were determined on this basis.

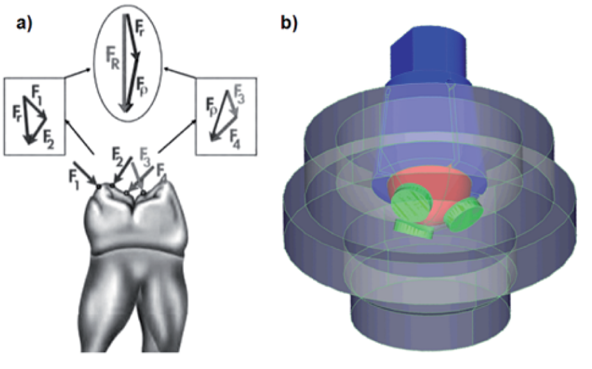

Fig. 2. Spatial system of forces in occlusal contacts (a) and geometry of the friction node in tribological tests of premolars and molars (b) [L. 9]

Rys. 2. Przestrzenny układ sił w kontaktach okluzyjnych (a) oraz geometria węzła tarcia w badaniach tribologicznych zębów przedtrzonowych i trzonowych (b) **[L. 9]**

The evaluation of resistance to movement in sliding friction allows the determination of coefficients of friction and the sizes of wear defects indicate the resistance of biomaterials to destruction as a result of concentrated contact. Using the classic Amontons' formula to determine the friction force T, with the same value of the occlusal force N, it can be indicated that the lower the value of the coefficient of friction, the lower the friction force causing destructive wear.

$$T = \mu N \quad (1)$$

T – friction force [N],
N – pressure force, which is also the force that balances the external load in occlusion conditions [N],
μ – coefficient of friction.

Mechanical impact processes prevail in contact between the oral cavity and the prosthetic restoration in the presence of saliva. Food in the mouth is exposed to the action of the teeth, sharp incisors and conical canines pierce and tear it, wider premolars and molars knead and grind it. Successive muscle contractions push the chewed bite toward the throat, elevate the larynx, and direct food into the esophagus. Knowledge about the occlusal contact and intercuspal relationships of both dental arches, in the intercuspal position or in the centric occlusion, is necessary in the case of natural dentition and reconstruction **[L. 26–35]**.

TEST RESULTS AND THEIR DISCUSSION

Microstructural tests of the chewing surfaces of acrylic teeth

The chewing surfaces of the teeth for dentures were evaluated based on photographs and SEM images. Examples of first molars (sixth teeth) from various manufacturers are presented (**Figs. 3–8**).

The chewing surfaces of the examined teeth are made more or less carefully, both when analyzing the shape in anatomical terms, and the microstructure of the cusps and grooves in the premolars and molars. It can be pointed out that the Postaris DCL and Gnathostar teeth have the most carefully reproduced shapes of the chewing surfaces. The shapes of the chewing surfaces of the teeth significantly influence the chewing process and the tribological interactions in the contact of opposing teeth.

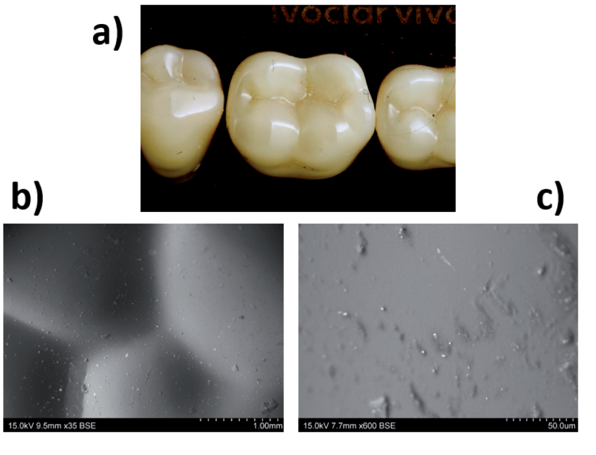

Fig. 3. Chewing surface of the Gnathostar tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 3. Powierzchnia żująca zęba Gnathostar: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

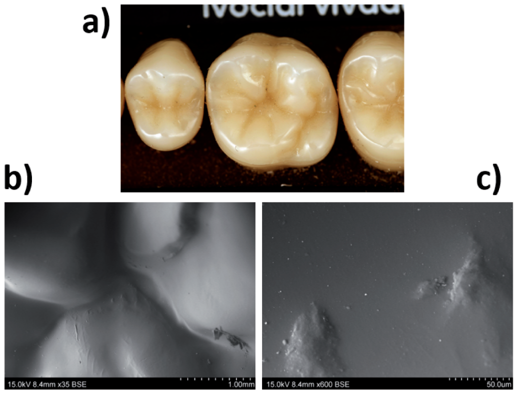

Fig. 4. Chewing surface of the Postaris DCL tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 4. Powierzchnia żująca zęba Postaris DCL: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

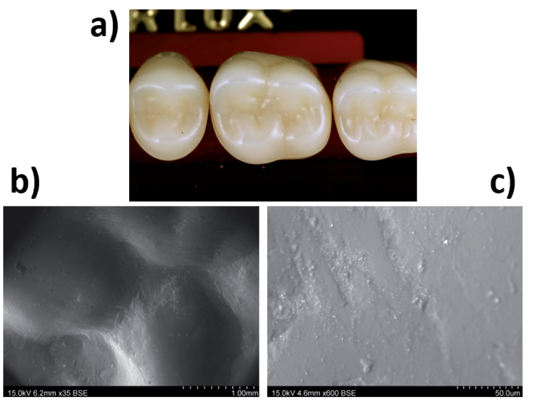

Fig. 5. Chewing surface of the Major Super Lux tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 5. Powierzchnia żująca zęba Major Super Lux: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

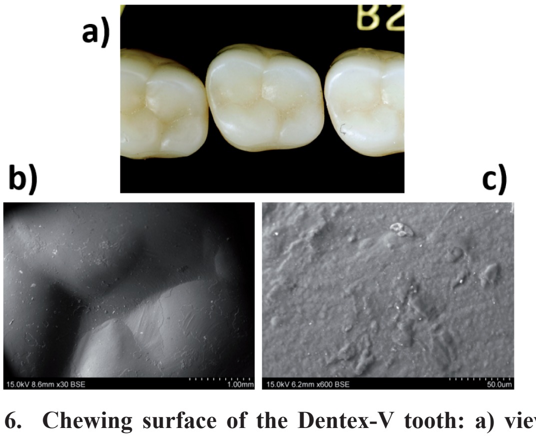

Fig. 6. Chewing surface of the Dentex-V tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 6. Powierzchnia żująca zęba Dentex-V: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

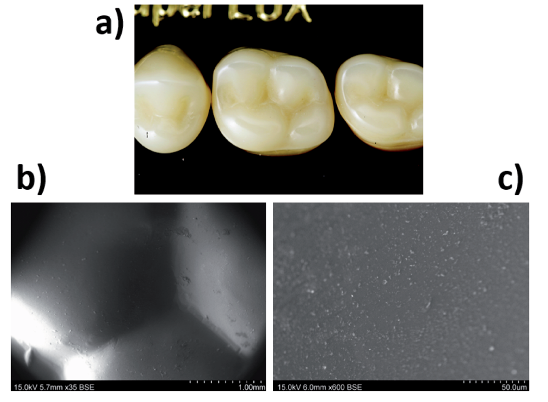

Fig. 7. Chewing surface of the Mifam Super Lux tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 7. Powierzchnia żująca zęba Mifam Super Lux: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

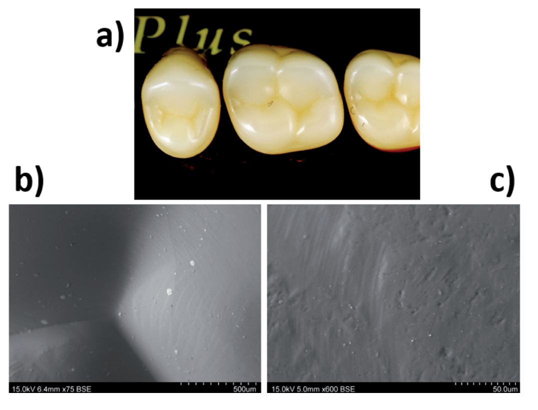

Fig. 8. Chewing surface of the Classic Plus tooth: a) view, b) SEM image of cusps and grooves, c) SEM image of the cusp slope

Rys. 8. Powierzchnia żująca zęba Classic Plus: a) widok, b) obraz SEM guzków i bruzd, c) obraz SEM zbocza guzka

Micromechanical tests of acrylic teeth

Micromechanical tests were preceded by microstructural tests using a Zeiss Stemi 508 optical microscope in axial and horizontal sections (**Figs. 9** and **10**). In these cross sections, acrylic teeth are characterized by a layered structure: a uniform internal structure and an external veneering layer. The veneering layer on the chewing surfaces is much thicker than the layers on the lateral surfaces.

The results of micromechanical tests performed on axial and horizontal sections of teeth allowed for the evaluation of microhardness, Young's modulus, and maximum depth of penetration in the following zones: in the outer (veneering) layer and in the

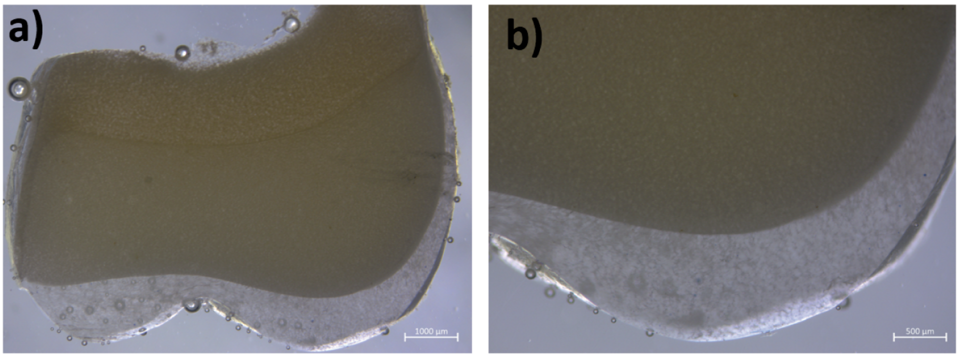

Fig. 9. Axial section of the Classic Plus tooth, perpendicular to the mandibular arch: a) general view, b) distal lingual cusp
Rys. 9. Przekrój osiowy zęba Classic Plus, prostopadły do łuku żuchwy: a) widok ogólny, b) guzek językowy dystalny

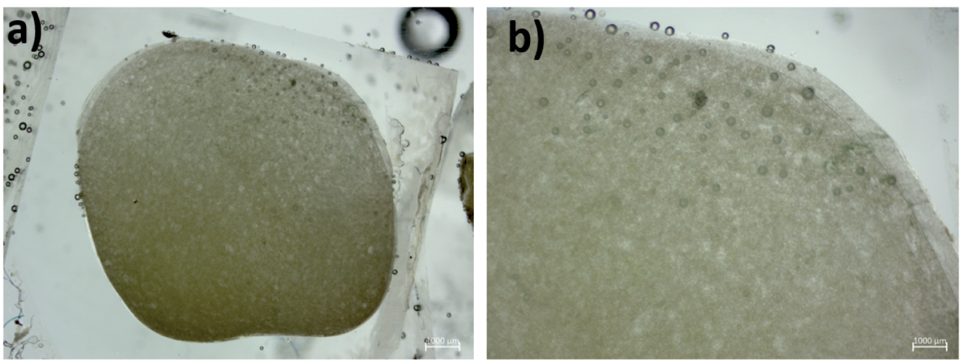

Fig. 10. Horizontal section of the Dentex-V tooth, perpendicular to the long axis: a) general view, b) buccal view
Rys. 10. Przekrój horyzontalny zęba Dentex-V, prostopadły do osi długiej: a) widok ogólny, b) widok od strony policzkowej

internal structure. Micromechanical parameters for individual teeth, for the tested zones, in specific sections, were determined as the average of 5 measurements (**Tab. 1** and **2, Fig. 11** and **12**).

The highest microhardness values in the axial and horizontal sections, both in the inner zone and in the veneering zone, are found in the Gnathostar teeth. In axial sections, the microhardness in the zone of the veneering layer is 257.31 MPa, and in the internal structure it is only slightly lower and has a value of 256.53 MPa. In horizontal sections, the Gnathostar microhardnesses differ slightly more: in the veneering – 252.67 MPa and inside the tooth – 255.42 MPa. For Gnathostar teeth, the highest microhardness value should be emphasized in the veneering zone, in the axial sections.

The Gnathostar teeth have the highest values of the longitudinal modulus of elasticity in the axial and horizontal sections. In axial sections, the highest value of all examined teeth: 4.76 GPa in the veneering layer, 4.84 GPa in the internal structure and in horizontal sections: 4.59 GPa in the veneering and 4.77 GPa in the internal structure.

In the evaluation of the microhardness value in the axial and horizontal sections, the next samples are Major Super Lux teeth, which in both sections are characterized by similar microhardness: in the axial section, in the veneering – 252.23 MPa and in the internal zone – 249.66 MPa, and in the horizontal section: in the veneering layer – 250.64 MPa and in the internal zone – 251.38 MPa. They also have quite high and similar Young's modulus values ranging from 4.61 GPa to 4.64 GPa.

The microhardness of the remaining acrylic teeth, i.e. Classic Plus, Dentex-V, Mifam Super Lux, and Postaris DCL, in both sections ranges from 239.78 MPa to 253.97 MPa. However, it should be emphasized that there are differences in Young's modulus values in these teeth. The longitudinal modulus of elasticity in axial sections has the highest values for Postaris DCL: in the veneering layer –4.67 GPa and in the internal

Table 1. List of micromechanical parameters in axial sections of acrylic teeth made using the Oliver and Pharr method
Tabela 1. Zestawienie parametrów mikromechanicznych w przekrojach osiowych zębów akrylowych wykonane metodą Olivera i Pharra

Material of tests		Metrology parameters	Hardness HV	Hardness HiT [MPa]	Young's modulus E [GPa]	Depth of penetration, hmax [nm]
Outer veneering layer	Gnathostar	Average value	23.83	257.31	4.76	6412.06
		Standard deviation	0.40	4.30	0.02	47.70
	Postaris DCL	Average value	22.53	243.32	4.67	6564.97
		Standard deviation	0.06	0.68	0.01	6.65
	Major Super Lux	Average value	23.36	252.23	4.61	6489.10
		Standard deviation	0.13	1.41	0.02	19.90
	Dentex – V	Average value	22.86	246.85	4.60	6538.59
		Standard deviation	0.28	3.00	0.02	28.70
	Mifam Super Lux	Average value	23.10	249.46	4.56	6522.38
		Standard deviation	0.04	0.43	0.01	7.82
	Classic Plus	Average value	23.32	251.83	4.82	6453.46
		Standard deviation	0.28	3.02	0.05	17.89
Internal structure	Gnathostar	Average value	23.76	256.53	4.84	6412.06
		Standard deviation	0.22	2.32	0.06	31.38
	Postaris DCL	Average value	22.21	239.79	4.69	6601.13
		Standard deviation	0.15	1.62	0.03	14.45
	Major Super Lux	Average value	23.12	249.66	4.63	6513.28
		Standard deviation	0.09	0.97	0.02	11.83
	Dentex – V	Average value	23.16	250.04	4.61	6510.27
		Standard deviation	0.40	4.36	0.04	50.79
	Mifam Super Lux	Average value	23.52	253.97	4.56	6479.06
		Standard deviation	0.10	1.05	0.01	14.89
	Classic Plus	Average value	22.57	243.69	4.81	6538.83
		Standard deviation	23.83	257.31	4.76	14.97

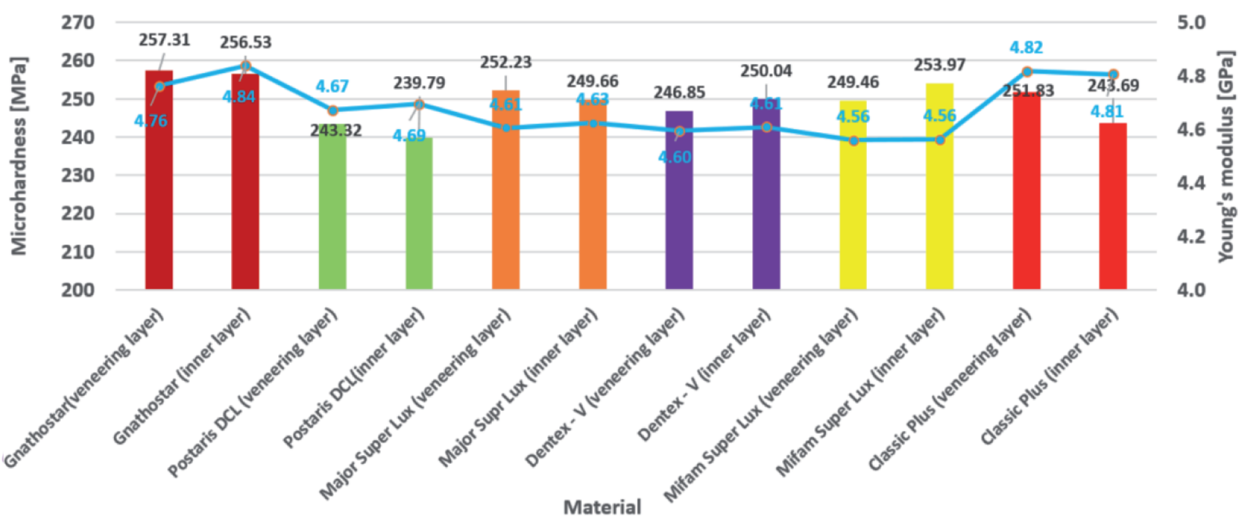

Fig. 11. Summary of micromechanical parameters of acrylic teeth in axial sections
Rys. 11. Zestawienie parametrów mikromechanicznych zębów akrylowych w przekrojach osiowych

Table 2. List of micromechanical parameters in horizontal sections of acrylic teeth made using the Oliver and Pharr method

Tabela 2. Zestawienie parametrów mikromechanicznych w przekrojach horyzontalnych zębów akrylowych wykonane metodą Olivera i Pharra

Material of tests		Metrology parameters	Hardness HV	Hardness HiT [MPa]	Young's modulus E [GPa]	Depth of penetration, hmax [nm]
Outer veneering layer	Gnathostar	Average value	23.40	252.67	4.60	6483.59
		Standard deviation	0.05	0.53	0.001	14.04
	Postaris DCL	Average value	22.61	244.17	4.71	6549.17
		Standard deviation	0.24	2.60	0.03	34.27
	Major Super Lux	Average value	23.26	250.64	4.64	6528.92
		Standard deviation	0.15	2.14	0.02	22.56
	Dentex – V	Average value	22.81	246.32	4.62	6537.36
		Standard deviation	0.40	4.27	0.03	48.90
	Mifam Super Lux	Average value	23.02	248.57	4.52	6542.60
		Standard deviation	0.22	2.42	0.04	31.61
	Classic Plus	Average value	22.47	242.66	4.57	6590.17
		Standard deviation	0.20	2.20	0.003	17.45
Internal structure	Gnathostar	Average value	23.66	255.42	4.77	6429.71
		Standard deviation	0.36	3.90	0.01	34.18
	Postaris DCL	Average value	22.54	243.36	4.70	6561.44
		Standard deviation	0.27	2.95	0.03	34.22
	Major Super Lux	Average value	23.28	251.38	4.62	6482.61
		Standard deviation	0.10	0.95	0.02	14.94
	Dentex – V	Average value	22.99	248.19	4.61	6531.06
		Standard deviation	0.10	1.08	0.001	12.32
	Mifam Super Lux	Average value	22.83	246.53	4.56	6547.99
		Standard deviation	0.03	0.35	0.02	7.56
	Classic Plus	Average value	22.53	243.22	4.75	6551.12
		Standard deviation	0.46	4.97	0.03	50.97

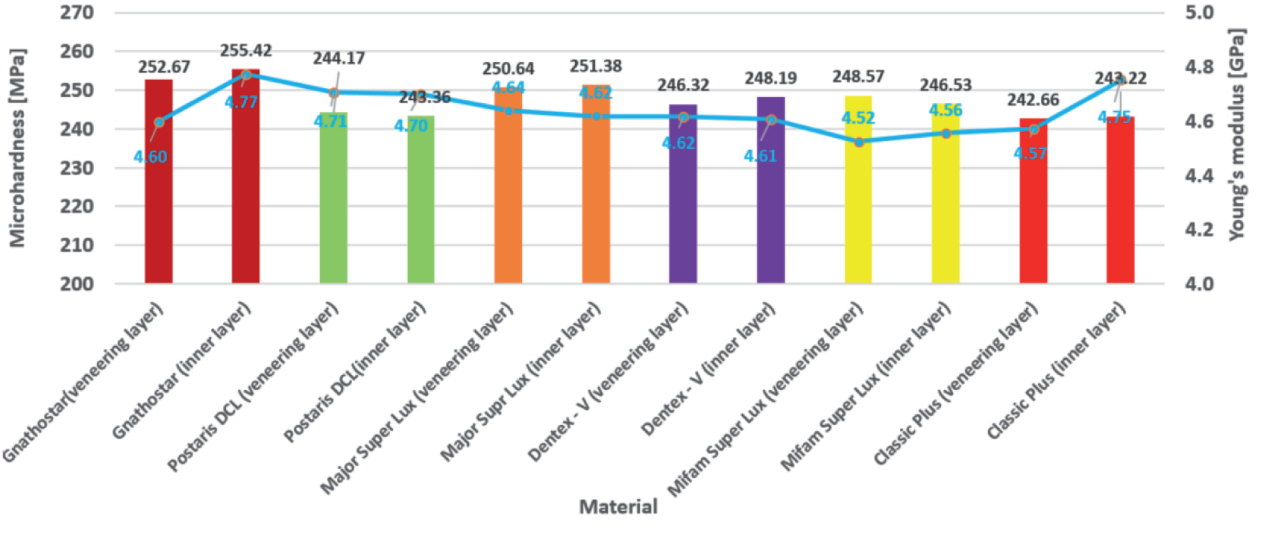

Fig. 12. Summary of micromechanical parameters of acrylic teeth in horizontal sections

Rys. 12. Zestawienie parametrów mikromechanicznych zębów akrylowych w przekrojach horyzontalnych layer – 4.69 GPa, and in horizontal sections, in the veneering layer – 4.70 GPa and in the internal structure – 4.71 GPa. The Young's modulus values of Classic Plus teeth are varied in axial sections: veneering layer – 4.82 GPa, internal layer – 4.81 GPa and in horizontal sections: veneering layer – 4.57 GPa, internal layer – 4.75 GPa. The remaining teeth: Dentex-V and Mifam Super Lux have similar values of Young's modulus in the veneering and internal layers in the axial sections, and also similar values in the horizontal sections. As regards the Dentex-V tooth, in the axial section they range between 4.60 GPa and 4.61 GPa and in the horizontal section between 4.61 GPa and 4.62 GPa. As for the Mifam Super Lux tooth, they were the lowest of all tested samples – in the axial section it was 4.56 GPa, and in the horizontal section the value ranged from 4.52 GPa to 4.56 GPa.

Higher Young's modulus values may be beneficial because the teeth are more rigid. This may be the case for Postaris DCL, Classic Plus, and Gnathostar teeth.

Tribological tests of acrylic teeth

The results of tribological tests of acrylic teeth made of 6 different materials, in cooperation with ZrO_2, showed different variations in the coefficients of friction (**Fig. 13**). Some materials achieved the maximum value of the coefficient of friction in the initial phase of the test, and then the coefficient of friction value decreased until it stabilized in the final phase – Gnathostar, Postaric DCL, Dentex-V and Classic Plus. In the remaining test nodes, the coefficient of friction increases and stabilization occurs only in the final phase of the test – Major Super Lux and Mifam Super Lux. Considering the final phase of the test, the materials were divided into 3 groups.

The first group consisted of materials with the lowest coefficient of friction: Gnathostar and Postaris DCL. In the case of Gnathostar samples, the most stable course of the coefficient of friction was observed among all tested materials over the entire research range, and it was in the range of 0.052–0.067 to stabilize at the value of 0.062. In turn, Postaris DCL teeth had a coefficient of friction in the range of 0.051–0.078, which stabilized at the lowest level of all tested materials, 0.058.

The second group showing slightly higher coefficient of friction values was the Dentex-V and Classic Plus materials. Taking into account Classic Plus, the coefficient of friction during the test was in the range of 0.059–0.086 and stabilized at the value of 0.080, and teeth made of the Dentex-V had a coefficient of friction during the test in the range of 0.066–0.102 and stabilized at a similar level of 0.078.

The last group, with the highest coefficient of friction values, was Mifam Super Lux and Major Super Lux. In the case of Mifam Super Lux acrylic

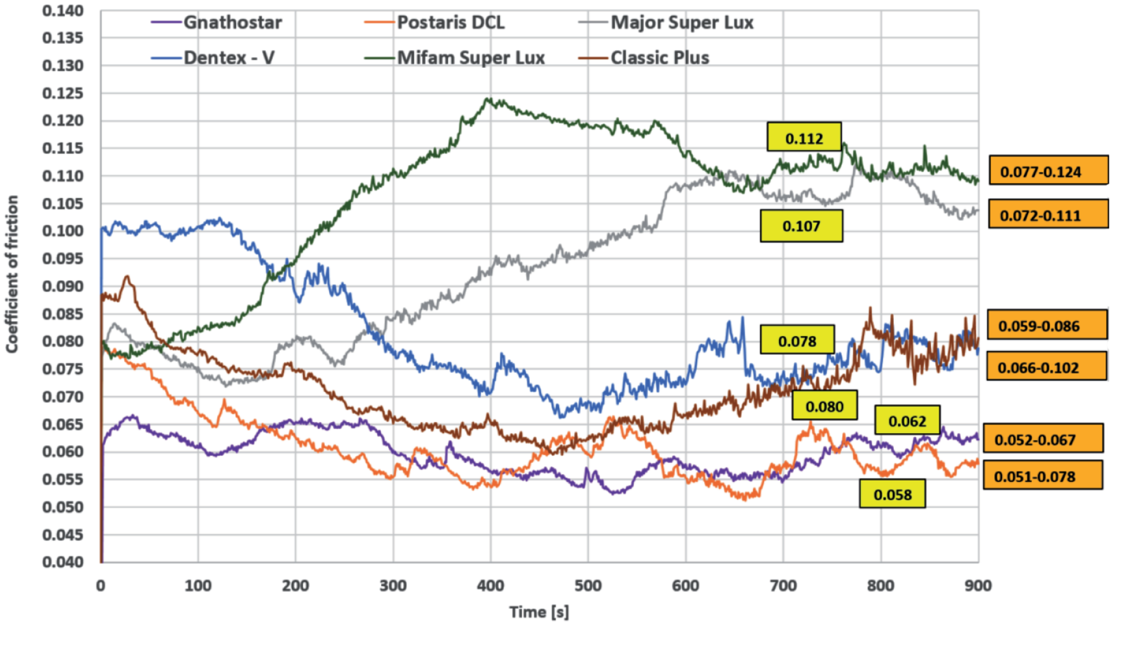

Fig. 13. Representative coefficients of friction of tested acrylic teeth in cooperation with ZrO_2
Rys. 13. Reprezentatywne współczynniki tarcia badanych zębów akrylowych we współpracy z ZrO_2

teeth, the coefficient of friction during the test was in the range of 0.077–0.124 and stabilized at 0.112. For the Major Super Lux teeth, the coefficient of friction was in the range of 0.072–0.111 and stabilized at the level of 0.107.

The results of the wear resistance tests for acrylic teeth made of various materials were evaluated on the basis of the average diameter of the wear defect (**Fig. 14**). The lowest wear resistance was found for the Dentex-V sample, the average diameter of the wear defect was 2.03 mm. The following materials had slightly better wear resistance: Mifam Super Lux, for which the average diameter of defect was 1.83 mm, Classic Plus, for a defect of 1.72 mm, Major Super Lux – 1.68 mm, and Postaris DCL, for which the average diameter of wear defect equals 1.65 mm. The highest wear resistance was found under sliding friction conditions in the presence of artificial saliva for Gnathostar teeth. The average diameter of the wear defect was 1.50 mm.

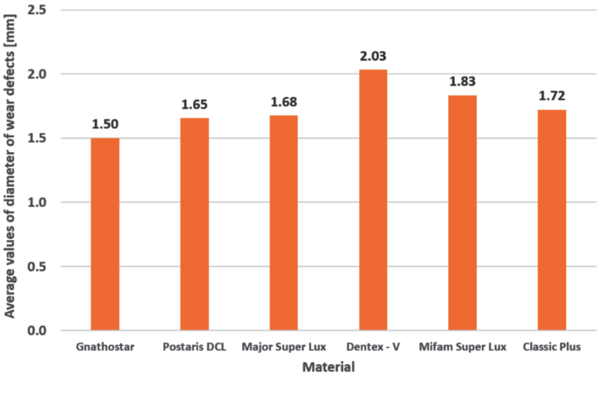

Fig. 14. Tests of wear resistance of acrylic teeth
Rys. 14. Badania odporności na zużycie zębów akrylowych

It can be concluded that in the tribological tests in the aspect of clinical applications, the best teeth for dentures were Gnathostar and Postaris DCL premolars and molars. They were characterized by the highest wear resistance in sliding friction and the lowest values of movement resistance when lubricated with artificial saliva. The least wear resistant teeth were Dentex-V and Mifam Super Lux, and the coefficient of friction of the highest values occurred with Mifam Super Lux and Major Super Lux teeth. The Classic Plus and Major Super Lux teeth had intermediate wear resistance. When using acrylic teeth dentures, a very important feature is their wear resistance, and the resistance to movement in sliding friction is slightly less important. Acrylic polymethacrylates, which are most often used in prosthetic reconstruction because of a number of advantages, have much poorer wear resistance than natural teeth and are subject to abrasion. The layered structure of natural teeth and their micromechanical parameters optimally protect them against wear under chewing and occlusion conditions **[L. 9, 26, 33, 35–41]**. Contact with acrylic teeth, which have a much poorer wear resistance, may result in tribological destruction of the prosthesis and a decrease in occlusion. That is why it is so important to evaluate and select acrylic teeth with the highest wear resistance.

CONCLUSIONS

The microstructural, micromechanical, and tribological tests carried out allow us to evaluate acrylic teeth for dentures in terms of the physiology of the chewing mechanism.

Microstructure analysis indicates the similarity of the biomaterials from which teeth are made, both in the veneering layer and in the internal structure. There are slight differences in the accuracy and thickness of the veneering layer between the examined teeth. They may affect the performance parameters of the prostheses.

Micromechanical tests and clinical observations allow us to conclude that a high value of the longitudinal elastic modulus significantly determines the optimization of adaptive contact under compressive and bending loads, which prevail during the biting and chewing cycle.

Dental tests on microhardness should continue, as there is no clear indication of its influence on contact tribology, as observed for Gnathostar, Classic Plus and Postaris DCL teeth.

Tests of resistance to tribological wear in sliding friction in the presence of Kserostemin artificial saliva clearly indicate that the tooth samples Gnathostar, Postaris DCL, and Major Super Lux are the most resistant.

The lowest coefficients of friction values were recorded in the presence of artificial saliva from Kserostemin for Gnathostar and Postaris DCL tooth samples.

Based on a full series of tests, it can be concluded that the Gnathostar and Postaris DCL teeth had the most optimal tribological features.

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