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Influence of introducing silver nanoparticles on tribological characteristics of soft liner

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ABSTRACT

Purpose: of this paper is to assess the influence of introducing silver nanoparticles to the material intended for denture lining on tribological properties of obtained composite and retention properties of elastic friction attachments made of it.

Design/methodology/approach: Studies of coefficient of frictions and forces conducted using a handle designed for this which allows exerting symmetrical pressure through elastomer samples on counterspecimen, applying different pressure forces and relative velocities of friction elements. The study of forces and retention of elastic friction attachments was conducted on the basis of our own methodology in an environment of artificial saliva.

Findings: Results of laboratory tests show that introducing 40 ppm of nanosilver does not influence coefficient of friction values. Simultaneously, some dependencies of coefficient of frictions on pressure forces values were observed, while no dependencies of coefficient of frictions on relative velocities of friction elements were shown. No practically meaningful influence of introducing nanosilver, pressure force or relative velocities of elements on friction force values was noted. Values of retention forces did not depend on the content of nanosilver.

Research limitations/implications: Limitations resulting from the specificity of the conditions of laboratory tests of retention characteristics do not allow to fully translate obtained results to expected results of clinical trials.

Practical implications: The studies show that introducing a small amount of nanosilver to soft lining material will allow to obtain elastic attachments with unchanged retention characteristics, but they will be characterized with increased antimicrobial resistance.

Originality/value: Study results of tribological properties of a new composite were presented. Own methodology of studying coefficient of friction and friction force of silicone rubber was presented here.

Keywords: Biomaterials; Friction; Implant; Silicone Rubber; Nanosilver; Overdenture

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MATERIALS

1. Introduction

Soft liners are frequently used for denture relining to distribute the forces transported onto mucosa during chewing. Elastic properties help to increase the comfort of patients and can support therapeutic treatment. Those materials are usually used in patients with: normal mucosa with an atrophied ridge thin atrophic mucosa, a sharp alveolar ridge and when the mucosa shows a small tolerance to the pressure applied by the dentures [1-4]. Due to the primary purpose of soft lining materials coefficient of friction of soft lining friction pair - titanium does not belong to typically measured properties. At the same time, friction of silicone rubbers significantly vary from friction properties of other solid materials like metals. Reasons for this include a low elasticity module and high internal friction of these materials [5-7].

In case of this type of materials tribological properties are mentioned usually only incidentally while considering wettability of silicones and acrylics, as large value of wettability degree of these materials favors insignificant adhesion of bacterial flap to its surface on one hand [8-9], and on the other hand it can influence the growth of friction between the materials and the mucous membrane due to worse wetting of dentures with saliva.

Even though lining materials are used mainly for traditional lining of complete dentures, there are also some experimental solutions, in which the use of silicone elastomers is suggested to stabilize overdenture using one or two implants. The purpose of this kind of solutions is the use of intramucosal support with simultaneous support of stabilization and retention of dentures by the use of elastic friction attachments in a way which prevents from implant overload [10-13]. Laboratory tests of this kind of attachments simultaneously show that the application of a silicone retention element despite generating small (in comparison to commercial solutions) retention forces is characterized by comparable or even better effectiveness, which is achieved by adequate use of material features and retention characteristics of this kind of attachments [14].

Pilot clinical trials confirm high effectiveness of these kinds of solutions [15]. In this kind of solutions the key role is played by values of coefficient of friction in the system of silicone rubber - metal and friction force value in the system of silicone rubber - saliva - metal. These values represent two extreme situations: the lack of wetting of the implant with saliva or very good and constant wetting of the implant with saliva. At the same time due to traditional areas of the application of these materials, there is no standardized methodology for these tests. Typical measurement methods of coefficient of friction used for metals or acrylic materials for denture plates, in this case cannot be adequately applied due to specific properties of these elastomers, such as: strong adhesion of the polymer to smooth surfaces or a low elasticity module. These properties significantly influence coefficient of friction values [5]. Literature also shows that coefficient of friction of soft rubber depends on factors such as: relative velocity of friction elements, pressure force values or the time of mutual contact of friction elements proceeding the initiation of relative movement [6].

At the same time, a basic problem connected with functioning of soft lining materials in the environment of the oral cavity is their colonization and penetration by microorganisms, such as fungus Candida albicans [16-17]. It lowers the durability of both the lining of traditional complete dentures [18] and experimental elastic friction attachments integrated with the linings [15]. Therefore, in relation to confirmed properties of silver nanoparticles, which show antimicrobial effect in materials designed for dentistry [19-20], studies on introducing nanosilver to soft materials of long-term denture linings were undertaken. These studies allowed to obtain materials which show increased antifungal effectiveness in in vitro tests [21], as well as relevant basic mechanical and usable properties [22].

In relation to expected usage of obtained composites to construct elastic friction attachments, the purpose of this work was to test the influence of introducing silver nanoparticles to soft lining materials for their tribological properties such as: coefficient of friction, friction force and retention characteristics of elastic attachments.

2. Materials and experimental procedures

In the studies we used a two-component silicone material, which is designed to make long-term soft denture linings Ufi Gel SC (Voco, Niemcy), and nanocomposite obtained by introducing to Ufi Gel SC silver nanoparticles. Mass content of silver nanoparticles in the composite was determined through the results of previous studies and it was 40 ppm. The method of introducing silver nanoparticles was described in detail in previous papers [21-22]. Silver nanoparticles suspension in hexan (Amepox, Łódź) with a mass content of 30 ppm was used as a source of silver nanoparticles. An average silver nanoparticles was 22.8 nm. Silver nanoparticles were introduced to both components of the material called Ufi Gel Base and Ufi Gel Catalist. Each component of the material was dissolved in hexan, the suspension of silver nanoparticles was introduced, and then the solvent was evaporated first at pressure lowered to 0.01 MPa in 50°C on a rotary evaporator (IKA RV-10), and then in a drier in 50°C at atmospheric pressure. After the evaporation of the solvent, the material components and nanocomposite were manually mixed, then plates with dimensions of 80 x 80 x 2.25 mm were crosslinked; a punch was used to cut 15 mm diameter and 2.25 mm height.

Titanium samples in the shape of a flat bar and with a cross-section of 2 x 30 mm made of titanium alloy Ti-6Al-4V and submitted to loose abrasive machining were used as a counterspecimen. Control of roughness of counterspecimen was conducted using a device called Form Talysurf Series 50 manufactured by Taylor Hobson Ltd. A surface of 2 mm x 2 mm was scanned with a resolution in the Y-axis of 0.01 mm (201 measurements were performed in each 10 μm). The following parameters were registered: Sa - arithmetic mean deviation of surface roughness height from the reference plane, Sp - the height of the highest peak of the surface, Sv - the depth of the lowest indentation of the surface, Sz - the average surface roughness for 10 points (five highest peaks and five lowest indentations).

Coefficient of friction studies were conducted using a Zwick testing machine with the use of especially constructed handle presented in Fig. 1, which allows to exert symmetrical pressure of elastomer samples on titanium counterspecimen. This handle constitutes a modified and improved version of the handle presented in a previous paper [23]. During the tests the force necessary to move the titanium sample, placed between silicone samples, which were glued to the handle sockets, was registered. Pressure force was realized through an aggravating element with a calibrated piezoresistive force sensor FlexiForce (Tekscan) which was fixed on a tripod attached to the handle. This action allowed for constant control and registration of the value of force applied on the elements using a pressing table. Force regulation was performed using a screw which caused movement of the mobile table. Smooth regulation of force was assured by the elastic properties of the silicone samples themselves. During the experiment four pressure force values were applied: F_N of 10, 20, 40 and 60 N, and six different relative velocities of friction elements: (v_t) of 5, 10, 20, 40, 80 and 100 mm/min. In order to consider the influence of the environment in the oral cavity on coefficient of friction and friction force, all measurements were performed in a dry environment and after introducing a sample of human saliva. Mixed saliva obtained from the department employees was used. Saliva was applied on titanium counterspecimen and on silicone samples, and then loading was immediately applied; the experiment was initialized with the titanium sample being taken out.

Obtained results were statistically analyzed. The influence of introducing silver nanoparticles, pressure force values and relative velocities of friction elements on coefficient of friction values (dry) and friction force (in the presence of artificial saliva) was analyzed. Verification of the assumption about homogeneity of variance was performed using the Bartel test ($p > 0.05$ so the variations were homogenous), and then variation analysis (ANOVA) for multivariable systems ($\alpha=0.05$) was performed. The following null hypothesis were verified:

- Applied content of silver nanoparticles does not differentiate the average;
- Pressure force does not differentiate the average;
- Movement velocity of titanium counterspecimen does not differentiate the average;
- There is no cooperation between the levels of pressure force and the type of material (presence of silver nanoparticles) influencing the average;
- There is no cooperation between the levels of pressure force and movement velocity of titanium counterspecimen influencing the average;There is no cooperation between the levels of movement velocity of counterspecimen and the type of material influencing the average;
- There is no cooperation between the levels of pressure force, type of material and movement velocity of titanium counterspecimen influencing the average;

In case of rejecting the null hypothesis, a post-hoc Newman-Keuls test was conducted.

The studies of retention characteristics of implant attachments were conducted on a Zwick universal testing machine. In order to conduct studies of retention characteristics of elastic models of friction attachments, a special handle was constructed, which allows to fix the samples and conduct the tests while maintaining axial force that extends the attachment (Fig. 2) [14]. In order to consider the influence of introducing saliva between cooperating surfaces on registered friction forces, the handle was equipped in environmental chamber partly filled (up to the attachment level) with saliva; this influence is important in case of the connection of frictional metal (implant part over the bone) and silicone rubber (retention element). To conduct the studies, implant models were prepared, the endings of which imitated implant abutments (Integcoefficientd Abutment): Garbaccio, Alpha-Bio. Three models of implants were prepared and they had different diameters and reference fragment geometry IA of actual implant (Fig. 2):

- Models with cylindrically shaped abutment (CIA) Φ =2.2 mm; Φ =2.8 mm;
- Models with cylindrical-conical abutment - (CCOIA);

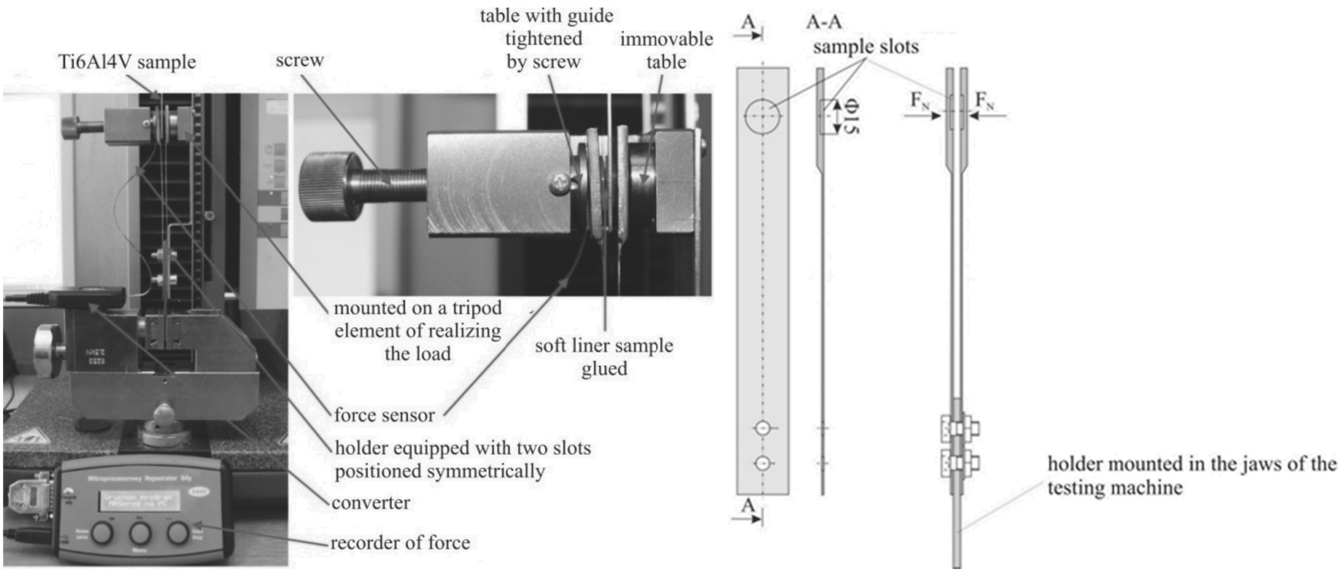

Fig. 1. A handle to test coefficient of frictions fixed in the jaws of the testing machine together with the element realizing the load and the handle scheme

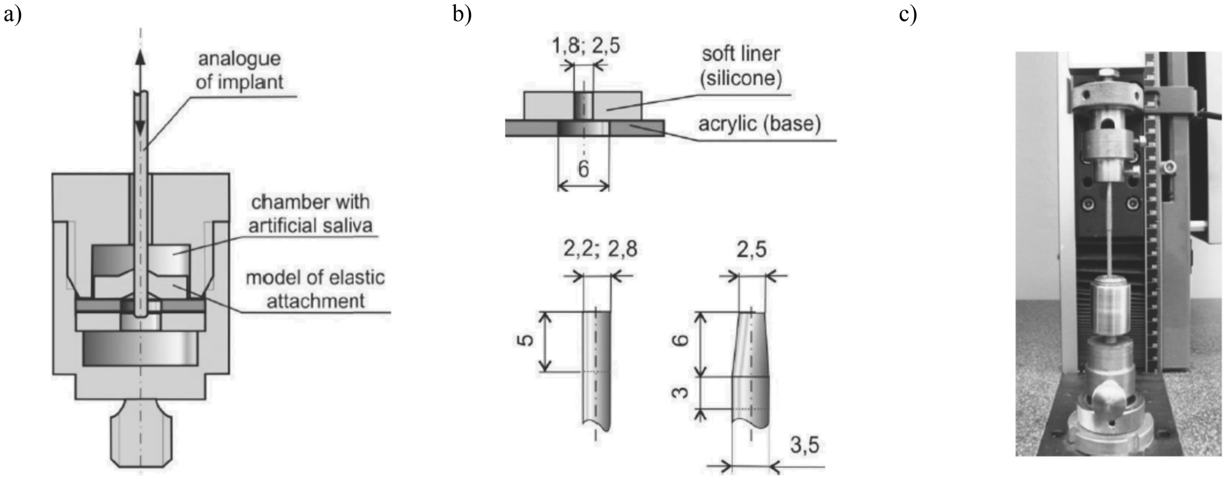

Fig. 2. The scheme of the handle used in the studies of retention characteristics of friction attachments (a), geometry and important (from the point of view of conducted experiment) dimensions of samples imitating implants and elastic models of retention elements (b), as well as the handle fixed in the testing machine during the experiment (c)

Models of elastic retention elements were made of silicone material Ufi Gel SC and nanocomposite with a mass content of silver nanoparticles of 40 ppm mixed with denture acrylic (Fig. 2b). Before applying silicone, a hole 6 mm in diameter was made to allow the "membrane" to bend during the test. In the silicone layer with an identical thickness of 2.5 mm for all samples, a centrically undersized hole IA (in relation to the diameter) was made. Its diameter was:

- 1.8 mm - for CIA implant models,
- 2.5 mm - for CCOIA implant models.

During the tests of elastic friction attachments generated force was registered in the course of movements of a titanium sample which imitated an implant in the attachment and its movement. Special attention was paid to axial setup of implant model in relation to the hole in the silicone sample. Cycle velocity was 15 mm/min. In the course of each test, after the first phase which included inserting the model into the hole, four preliminary cycles with increments of 2.5 mm were performed. It allowed to stabilize the attachment and relaxing stresses of pressured silicone. In the course of the fifth cycle the titanium sample was taken out of the attachment (return to the primary setup). In the analysis the part of the last cycle, starting from obtaining the equilibrium position (F=0 N) to complete separation of cooperating elements, was considered as a attachment retention characteristic [14]. A characteristic presented in such a way corresponds to actual behavior of a retention element in the course of dropping the denture with force simultaneous to axis IA.

Force by which friction force is overcome and implant model movement is started in relation to elastomer membrane was adopted as retention force F_R of tested attachments. Retention work (W_T) was determined by the calculation of the field below the retention characteristics [14].

Then, statistical analysis of the influence of introducing silver nanoparticles to the material and retention force F_R and retention work W_T of applied implant model was conducted.

Verification of the assumption about homogeneity of variance was performed using the Bartel test ($p > 0.05$ so the variations were homogenous), and then variation analysis (ANOVA) for multivariable systems (α=0.05) was performed. The following null hypothesis were verified:

- nanoparticles content does not differentiate the averages;
- the type of implant model does not differentiate the averages;
- there is no cooperation between implant model influencing the average;

In case of rejecting the null hypothesis, a post-hoc Newman-Keuls test was conducted.

3. Results and discussion

The results of roughness measurements were presented in Table 1.

A selection of the results of coefficient of friction studies conducted without saliva were presented in Table 2. The results of statistical assessment of obtained results were presented in Table 3 and Fig. 3. No influence of introducing silver nanoparticles into the material on coefficient of friction was observed; no influence of relative velocity of friction elements on coefficient of friction was noted. However statistically strong influence of pressure force on coefficient of friction was observed; it decreased together with the growth of pressure force. Average values of coefficient of friction for a pressure force of 10 N were included in the range of 3.59 to 3.85, for a pressure force of 20 N - 2.26 to 2.74, for a pressure force of 30 N - 1.54 to 1.73, and for a pressure force of 60 N - 1.0 to 1.13.

Table 1.
The results of roughness measurements of the samples with titanium surfaces

Parameter, µm			
S_a	S_p	S_v	S_z
0,42	2,9	5,12	6,28

Table 2.
A selection of coefficient of friction values obtained in the course of studies conducted without saliva*

Nanosilver concentration, ppm	Relative velocity of the elements, mm/min	Coefficient of friction, μ			
		Normal force 10 N	Normal force 20 N	Normal force 30 N	Normal force 60 N
0	5	3.69±0.20 [A]	2.54±0.26 [B]	1.58±0.20 [C]	1.07±0.06 [D]
	10	3.62±0.33 [A]	2.37±0.24 [B]	1.65±0.15 [C]	1.00±0.05 [D]
	20	3.70±0.27 [A]	2.38±0.29 [B]	1.54±0.10 [C]	1.04±0.07 [D]
	40	3.85±0.31 [A]	2.26±0.21 [B]	1.64±0.15 [C]	1.09±0.08 [D]
	80	3.82±0.31 [A]	2.66±0.26 [B]	1.62±0.13 [C]	1.09±0.06 [D]
	100	3.80±0.22 [A]	2.74±0.18 [B]	1.60±0.09 [C]	1.04±0.09 [D]
40	5	3.59±0.23 [A]	2.44±0.16 [B]	1.63±0.15 [C]	1.08±0.07 [D]
	10	3.61±0.10 [A]	2.42±0.16 [B]	1.63±0.13 [C]	1.13±0.09 [D]
	20	3.70±0.16 [A]	2.38±0.11 [B]	1.73±0.15 [C]	1.10±0.04 [D]
	40	3.69±0.20 [A]	2.50±0.23 [B]	1.70±0.14 [C]	1.11±0.06 [D]
	80	3.68±0.15 [A]	2.45±0.13 [B]	1.70±0.12 [C]	1.07±0.09 [D]
	100	3.71±0.26 [A]	2.39±0.14 [B]	1.72±0.16 [C]	1.03±0.05 [D]

* Average values with the same capital letters in superscript (A-D) for each row do not vary from one another in statistically significant way (p>0.05)

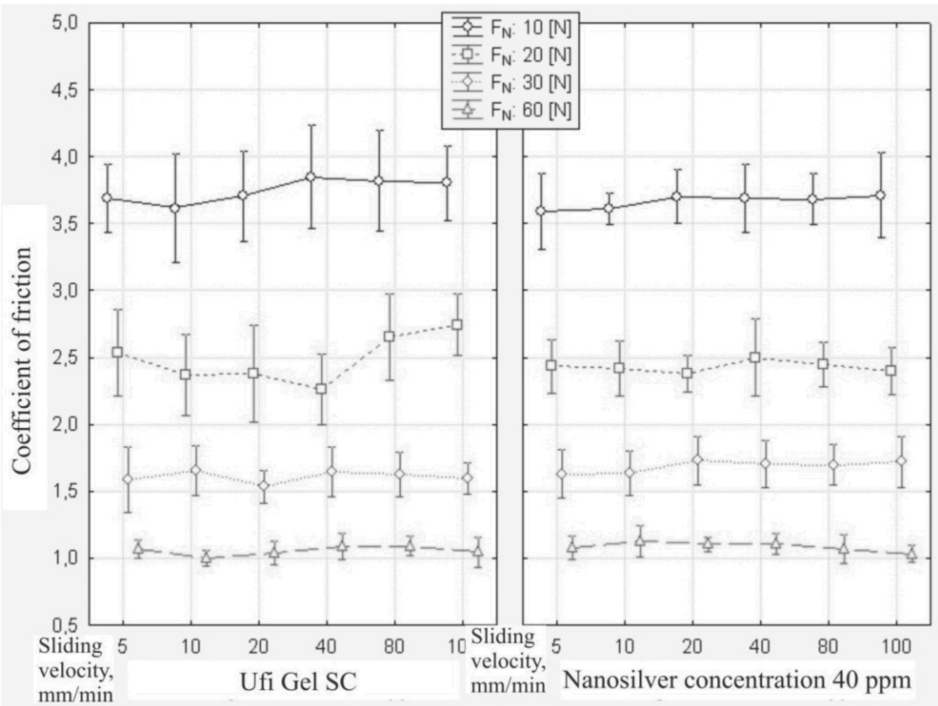

Fig. 3. A selection of coefficient of frictions obtained for samples made of UG material and nanocomposite with mass content of nanosilver of 40 ppm (without saliva) in the function of relative velocity of friction elements for four different pressure force values. Confidence interval was indicated with markers

Table 3.
The results of statistical assessment of the influence of nanosilver concentration, pressure force and relative velocity of friction elements on average values of coefficient of friction (without saliva) performed using ANOVA test ($p< 0.05$)

	Sum of squares	Degree of freedom	Mean square	F-test statistic value	p
Nanosilver concentration	0.004	1	0.004	0.14	0.7121
Normal force	235.035	3	78.345	2513.06	**0.0000**
Velocity of the elements	0.223	5	0.045	1.43	0.2148
Nanosilver concentration × normal force	0.265	3	0.088	2.43	0.0595
Nanosilver concentration × velocity of the elements	0.202	5	0.040	1.29	0.2686
Velocity of the elements × normal force	0.418	15	0.028	0.89	0.5711
Nanosilver concentration × velocity of the elements× normal force	0.496	15	0.033	1.06	0.3958

Table 4.
The results of statistical assessment of the influence u_{AgT}, pressure force and relative velocity of friction elements on average friction force values in the presence of saliva performed using ANOVA test ($p<0.05$)

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
Nanosilver concentration	0.066	1	0.066	2.52	0.0567
Normal force	0.325	3	0.108	9.54	**0.0000**
Velocity of the elements	0.048	5	0.010	0.85	0.5132
Nanosilver concentration × normal force	0.040	3	0.013	1.18	0.3204
Nanosilver concentration × velocity of the elements	0.035	5	0.007	0.61	0.6895
Velocity of the elements × normal force	0.242	15	0.016	1.42	0.1404
Nanosilver concentration × velocity of the elements× normal force	0.263	15	0.018	1.54	0.0929

Table 5.
A selection of friction force values obtained in the course of studies conducted in the presence of human saliva

Nanosilver concentration. ppm	Relative velocity of the elements. mm/min	Force of friction. N			
		Normal force 10 N	Normal force 20 N	Normal force 30 N	Normal force 60 N
0	5	$0.61±0.07^{A}$	$0.63±0.07^{A}$	$0.77±0.08^{B}$	$0.75±0.09^{B}$
	10	$0.59±0.05^{A}$	$0.64±0.07^{AB}$	$0.75±0.06^{B}$	$0.76±0.13^{B}$
	20	$0.66±0.12^{A}$	$0.66±0.10^{A}$	$0.77±0.08^{A}$	$0.67±0.11^{A}$
	40	$0.67±0.05^{AB}$	$0.72±0.14^{AB}$	$0.61±0.13^{A}$	$0.78±0.10^{B}$
	80	$0.54±0.05^{A}$	$0.78±0.10^{B}$	$0.75±0.06^{B}$	$0.75±0.16^{B}$
	100	$0.70±0.13^{A}$	$0.68±0.04^{A}$	$0.79±0.10^{A}$	$0.78±0.11^{A}$
40	5	$0.79±0.09^{A}$	$0.69±0.13^{A}$	$0.74±0.07^{A}$	$0.66±0.11^{B}$
	10	$0.60±0.21^{A}$	$0.74±0.05^{B}$	$0.76±0.06^{B}$	$0.76±0.18^{B}$
	20	$0.64±0.11^{A}$	$0.74±0.10^{A}$	$0.75±0.16^{A}$	$0.77±0.11^{A}$
	40	$0.69±0.17^{A}$	$0.78±0.09^{A}$	$0.79±0.11^{A}$	$0.83±0.05^{B}$
	80	$0.69±0.14^{A}$	$0.72±0.11^{AB}$	$0.83±0.08^{B}$	$0.69±0.15^{AB}$
	100	$0.73±0.06^{A}$	$0.74±0.08^{A}$	$0.73±0.05^{A}$	$0.75±0.10^{A}$

* Average values with the same capital letters in superscript (A-B) for each row do not vary from one another in statistically significant way ($p>0.05$)

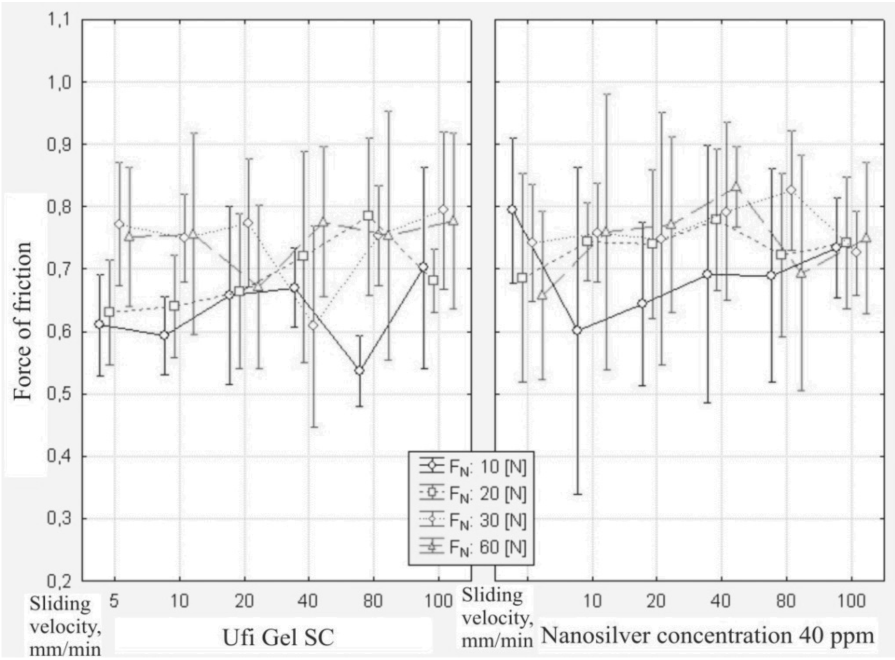

Fig. 4. A selection of coefficient of frictions obtained for samples made of UG material and nanocomposite with a nanosilver mass content of 40 ppm (in the presence of saliva) in the function of relative velocity of friction elements for four different pressure force values. Confidence interval was indicated with markers.

A selection of the results of the studies of friction force conducted with natural human saliva were presented in Table 4. The results of statistical assessment of obtained results were presented in Table 5 and Fig. 4. Obtained average values of friction force did not change in statistically significant way after introducing silver nanoparticles into the material, or with the change of relative velocity of friction elements, but they increased in statistically significant way together with increasing pressure force. No influence of particular factors on the average values of friction force values was observed.

A selection of the results of retention force measurements was presented in Table 6. The results of statistical assessment of obtained results were presented in Fig. 5a and in Table 8. The application of different models of implants influenced differentiation of retention force generated by elastic attachments in a statistically significant way. Obtained retention forces ranged from 2.18 (CIA Φ=2.2 mm) to 2.63 N (CIA Φ =2.8 mm). Introducing 40 ppm silver nanoparticles into the composite did not influence obtaining retention force values in a statistically significant way.

A selection of obtained retention works was presented in Table 7. The results of statistical assessment of obtained results were presented in Fig. 5b and in Table 9. The application of different models of implants strongly influenced obtaining values of complete retention work, which ranged from 7.6 $\times 10^{-3}$ to 9.04 $\times 10^{-3}$ [J], however the lowest values were obtained as a result of applying implant model of CIA Φ=2.2 mm, and the highest with CIA Φ=2.8 mm. Introducing 40 ppm silver nanoparticles into the composite did not influence obtaining complete retention work values in a statistically significant.

Table 6.
A selection of average values (together with standard deviations) of retention forces of elastic friction attachments (F_R)*

Type of implant model	Retention force. N	
	0 ppm	40 ppm
CIA Φ=2.2 mm	2.20±0.06 [a]	2.18±0.15 [a]
CIA Φ =2.8 mm	2.63±0.08 [b]	2.58±0.15 [b]
CCOIA	2.60±0.13 [b]	2.52±0.14 [b]

* Average values with the same capital letters in superscript (a-b) for each column do not vary from one another in statistically significant way (p>0.05)

Table 7.
A selection of average values (together with standard deviations) of complete retention work of elastic friction attachments (W_T).*

Type of implant model	Total work of retention. $\times 10^{-3}$ [J]	
	0 ppm	40 ppm
CIA 2.2 mm	7.60±0.09[a]	CIA 2.2 mm
CIA 2.8 mm	8.99±0.20 [b]	CIA 2.8 mm
CCOIA	8.71±0.19 [c]	CCOIA

* Average values with the same capital letters in superscript (a-c) for each column do not vary from one another in statistically significant way (p>0.05)

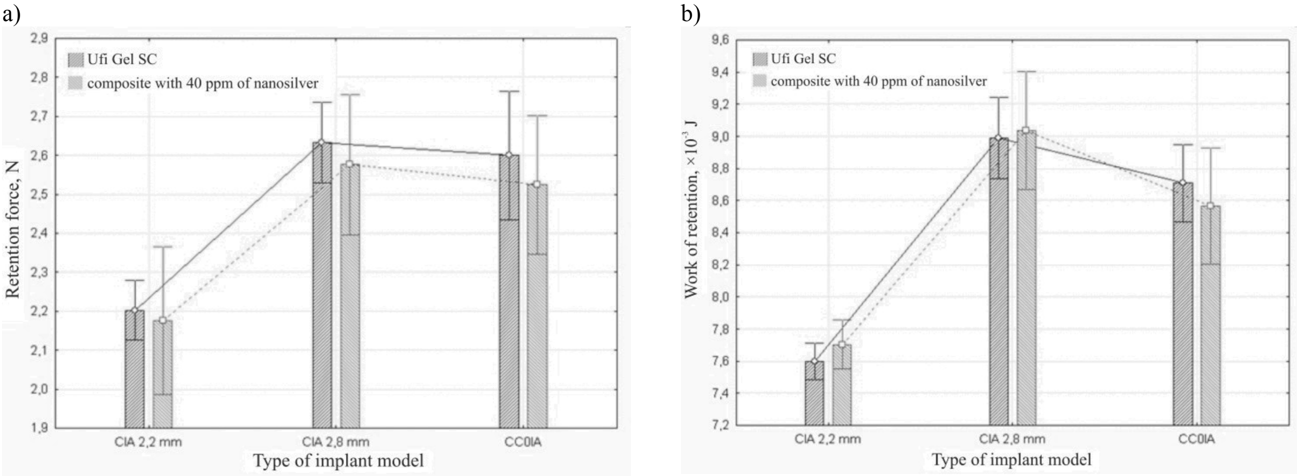

Fig. 5. A selection of the results of studies of retention forces (a) and retention works (b) obtained for elastic friction attachments made of UG material and nanocomposite with a nanosilver mass content of 40 ppm using different implant models. Confidence interval was indicated using markers

Table 8.
The results of statistical assessment of the influence of nanosilver concentration and applied implant model on average retention force values performed using ANOVA test ($p< 0.05$).

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
Nanosilver concentration	0.021	1	0.021	1.34	0.2576
Type of implant model	1.044	2	0.522	33.73	0.0000
Nanosilver concentration × type of implant model	0.003	2	0.002	0.10	0.9031

Table 9.
The results of statistical assessment of the influence of nanosilver concentration and applied implant model on average retention work values performed using ANOVA test ($p< 0.05$).

	Sum of squares	Degrees of freedom	Mean square	F-test statistic value	p
Nanosilver concentration	0.000	1	0.000	0.00	0.9865
Type of implant model	9.891	2	4.946	108.60	0.0000
Nanosilver concentration × type of implant model	0.083	2	0.042	0.91	0.4149

4. Discussion

Antimicrobial properties of soft liner Ufi Gel SC compared in this paper [21] with composite material with a nanosilver mass content of 40 ppm showed an increased antimicrobial effectiveness of the composite. The results for Ufi Gel SC material obtained in this study correspond with the results of other authors [24] and they show that the application of soft lining materials can intensify the process of fungal growth by 23.4% (in comparison to a positive control). The antifungal efficiency (AFE) of composite with 40 ppm of nanosilver was 31.5%. At the same time these properties of modified material, such as sorbtion, solubitity and bond strength did not change, while the hardness in Shore A scale decreased from 31 Shore A units to 27.7 Shore A units [22]. Such a insignificant decrease of hardness while maintaining other properties of the material should be considered beneficial from the point of view of the rehabilitation function of the material. Further increase of nanosilver concentration caused increased antimicrobial effectiveness, however significant deterioration of mechanical and usable properties was observed [21,22]. In relation to the obtained results of the studies of tribological properties conducted for the application of composites to make elastic friction attachments, material with a nanosilver mass content of 40 ppm was chosen.

In light of previously conducted studies of other nanocomposite properties [22], the lack of influence of introducing a small amount of silver nanoparticles into the composite on coefficient of friction, friction force and retention characteristics was compliant with the expectations. Very high properties of coefficient of friction obtained in a dry environment, depending on pressure force values, should be justified by the features of silicone rubber itself. The material strongly attached to the smooth surface of titanium sample as a result of adhesion forces. As a consequence, in the course of the experiment friction force did not increase proportionally with the increase of pressure force. For the highest values of pressure force, the influence of adhesion of silicone to metal on complete measured friction force was relatively lower than for the lowest values of pressure force, for which measured friction force was caused mainly by the adhesion of the sample to the surface of a titanium flat bar - therefore very high coefficient of friction values were obtained. After introducing it between cooperating saliva surfaces, small friction force values were obtained. In this case saliva was introduced between two cooperating surfaces with low roughness and it works as a lubricating agent. A classical model of dry friction cannot be applied in this case; but we deal with mixed friction, with significant majority of fluid friction or with fluid friction. Outer friction is changed for inner friction of lubricant, and friction force depends on the properties of the lubricating agent, and not on the properties of cooperating surfaces. Fluid coefficient of friction value is small and it depends on the thickness of the lubricating fluid layer, its stickiness and in some cases on its relative velocity of friction elements. In the analyzed case, the influence of introducing silver nanoparticles into the composite on friction force values was not proven. At the same time, statistically significant increase of friction force values with the increase of pressure force can be justified by the fact that the increase of pressure caused pushing a larger amount of saliva out of the system, which could have deteriorated lubricating conditions. Changes of friction force values were rather small in relation to the values, so they do not have practical significance.

Studies of coefficient of frictions and friction forces were conducted for two extreme situations: very good lubrication with saliva and the lack of lubrication with saliva. They show the range in which the presence of saliva might influence the properties of elastic attachments. However in reality such good lubrication of implants with saliva does not exist, as it occurred in the studies of friction forces due to the fact that an elastic attachment pulls off the excess of saliva from the surface of implants in the course of putting the denture on or using it, and it works similarly to a car wiper. On the other hand, it is impossible to maintain dry and clean implants. Therefore, tests of denture stabilizing systems conducted on physical models in the presence of saliva provide more precise and actual information regarding functioning of elastic friction attachments. On their basis, no influence of introducing silver nanoparticles into the composite on the values of generated retention forces and retention works, which has to be done in order to cause attachment separation, was observed. It is compliant with the expectations because proven differences in mechanical properties of Ufi Gel SC and the nanocompisite were insignificant [22], while retention properties of elastic attachments significantly depend on pressure force generated by elastic attachments on implants, while the pressure force depends on mechanical properties of the material used to construct the attachment. The second factor which influences retention force and work of the attachments included properties of a lubricating agent (saliva), which have no relation with the conducted modification procedure.

Therefore, it should be stated that introducing 40 ppm of silver nanoparticles does not influence in a significant way the properties of materials related to the functioning of elastic friction attachments, such as: coefficient of friction and friction force, as well as retention force and retention work of elastic friction attachments.

5. Conclusions

The results of investigations and their interpretation lead to the following conclusions:

1. The introducing 40 ppm of silver nanoparticles does not influence in a significant way to the coefficient of friction and friction force of the rubber - titanium couple.
2. The introducing 40 ppm of silver nanoparticles does not influence in a significant way the properties of materials related to the functioning of elastic friction attachments, such as: retention force and work of retention of elastic friction attachments.
3. It should be noted that increasing the concentration above 40 ppm silver could affect the tribological characteristics because it causes change in mechanical properties such as hardness and elastic modulus shown in [22]. These changes probably would affect negatively the characteristics of elastic frictional attachments and cause to reduce the work of retention and the retention force. In the present article, however, has not been studied materials with higher concentrations of nanosilver because previous studies have shown insufficient for soft relining bond strength to the denture base materials.

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