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Durability evaluation of a friction couple intended for implantological stabilization of complete dentures

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The paper presents the results of the study of the titanium implant–elastomeric membrane attachment, conducted from the point of view of potential utilization of the results in forecasting the durability of retention elements representing a new solution of dentures based on implants. The examination was carried out using a device designed by the author, which allowed the simulation of the process of inserting and removing dentures. Titanium counter specimens, simulating implants, were subjected to surface modification through their sandblasting with 350 μm and 500 μm abrasives, so as to diversify their roughness. The elastomeric membranes constituting a retention element of the attachment were made of a silicone material, Molloplast B. The influence of the number of cycles (one cycle meaning one insertion and removal of a denture) on the attachment's retention force was studied. In order to better reflect the natural conditions, the device was equipped with a chamber which made it possible to perform the examination in an artificial saliva environment.

The study has shown that the application of the polymer material Molloplast B for constructing the new type retention elements of dentures based on implants ensures practically constant values of the attachment's retention force in the required 6-month utilization period. After the time of denture usage, being eight times longer than originally assumed, the loss of retention force does not exceed 43% in any of the attachments investigated and the retention force values still allow the attachments to operate, although their effectiveness is partly reduced.

Key words: *implant, overdenture, liners, complete denture, silicone rubber, tribological wear*

1. Introduction

One of the methods applied to increase the availability of implantological treatment of edentulousness are overdentures based on a small number of implants. By reducing the number of implants, a considerable cost reduction has been achieved [5]. However, the results diverge from those obtained while applying bridges resting on many implants. In spite of continuing the improvement of overdenture structures resting on two dental implants, the results achieved so far do not guarantee a high patient satisfaction level [1]–[4]. The solutions proposed considerably improve the denture retention, but a reduction in the number of implants, in the case of the existing methods of the suprastructure connection with an implant, results in a significant increase of load imposed on the implants. Such a situation is conducive to the bone tissue atrophy and frequently leads to mechanical destruction of implants and elements fixing the denture, or to pathological changes of tissues in the implant's anchoring areas [6]–[9]. The works aimed at minimizing the above-mentioned unfavourable phenomena have led to devising a new concept of a biocompatible friction-membrane attachment enabling a considerable improvement of the denture functioning conditions (figure 1) [10]–[12].

In the solution proposed, the retaining element consists of an elastic ring placed directly in a seating prepared in the denture whose ring cooperates with a titanium implant. The making of the ring from materials possessing appropriate mechanical properties and an analysis of the friction phenomena taking place in

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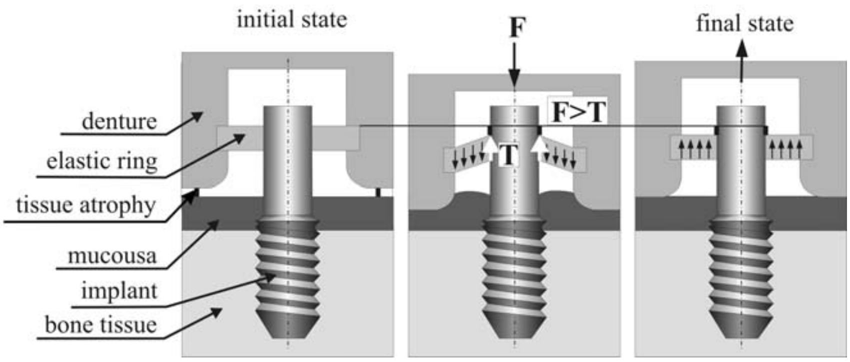

Fig. 1. The principle of functioning of the attachment enabling movements of the denture, depending on the mucous membrane resilience – adjustment of the denture location to the atrophy of the denture foundation

the titanium–elastomer couple aim at facilitating the design of an implant attachment which would adjust the denture position to atrophic changes in the denture base. However, the determination of durability of an elastomeric element juxtaposed with a rough surface of a "hard" implant still remains a fundamental problem.

The paper presents the results of durability tests of the titanium–elastomer attachment, which allow a preliminary evaluation of the tribological wear of selected attachments based on the changes recorded in the attachment retention force, depending on the number of cycles of the denture insertion and its removal from an implant.

a) b)

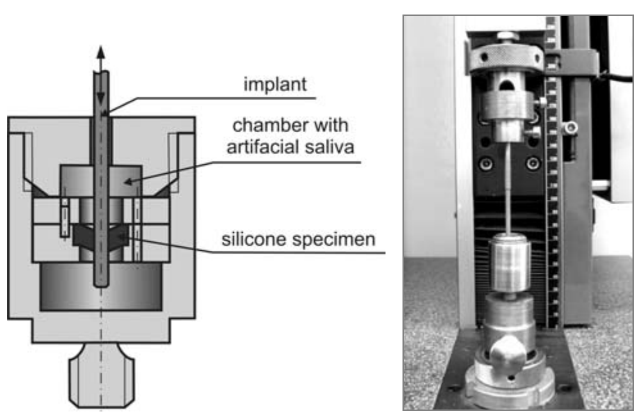

Fig. 3. Device used for retention tests of the elastomeric–titanium attachment equipped with chamber filled in with artificial saliva (a) and a test bench for tests with the device fixed in the jig of the strength test machine (b)

2. Research methodology

For fatigue tests, a testing stand was constructed according to the author's own design (figure 2). The device was adjusted to the installation of an attachment intended for examining the retention forces. In this device, a silicone specimen was fixed (figure 3a). A titanium specimen (implant) was fixed in a moveable vice,

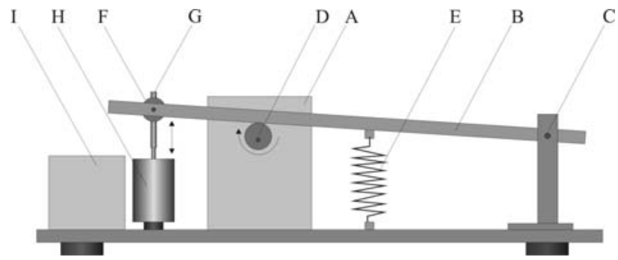

Fig. 2. Schema of a device used for fatigue tests: A – engine with gearbox, B – arm fixed on a bearing in a stand (C), D – shaft with a ring assembled eccentric, E – spring, F – small vice assembled on the bearing for fixing the sample simulating an implant, G – sample, I – cycle counter, H – a device enabling carrying out experiments in the environment of artificial saliva

which enabled additional simulation of small lateral movements of a titanium counter specimen (implant) occurring during the operation of the attachment. Cyclic loading of the specimen was realized through changing the motor rotation into a reciprocating motion of the implant. The experiment was conducted in an artificial saliva environment.

The silicone specimens were made of the Molloplast B material. The outer diameter of the specimens was 6.5 mm and their height was 3.5 mm. The diameter of the inner hole (prepared for the implant) was 1.8 mm. Titanium implant models were made of alloy Ti6Al4V, and subjected to surface modification through sanding.

Five attachments were tested for each of the following implant types: 2.65 mm implant sandblasted with abrasive of 350 μm (P350); 2.85 mm one sandblasted with abrasive of 350 μm; 2.65 mm one sandblasted with abrasive of 500 μm (P500); and 2.85 mm one sandblasted with abrasive of 500 μm.

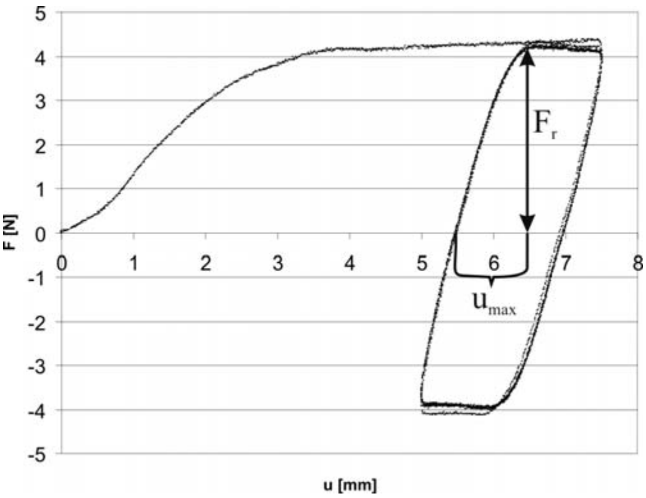

Fig. 4. Example of characteristics of the attachment achieved for Molloplast B and a titanium implant of a 2.65 mm diameter sandblasted with a 500 μm abrasive

The loss of retention force caused by tribological wear of the elastomeric membrane during motions of the titanium counter specimen was assumed to be the criterion of the attachment durability evaluation. The implant pitch of 4.5 mm was selected so as to reflect the real friction distance between the implant's part over the bone and the membrane during positioning the denture in place or its removing. One cycle comprises one insertion and one removal of the denture from its point of operation. It was assumed that replacement of the elastomeric element would take place during denture rebasing (every six months), with an average patient inserting the denture 3–6 times a day. The attachment should therefore work without significant losses in the retention force for approximately 1,200 cycles. Bearing in mind the fact that not all patients obey doctors' instructions, it was considered appropriate to examine the retention force loss in a further period of potential utilization of the attachment (up to 10,000 cycles). Measurements of the retention force were made after 200, 400, 800, 1,200, 1,600, 2,000, 2,400, 3,000, 4,000, 5,000, 6,000, 7,500, 9,000 and 10,000 cycles. Retention tests were carried out with a Zwick strength tester using a specially constructed attachment, equipped with a chamber filled with artificial saliva (figure 3). An example of the attachment characteristics is presented in figure 4. The retention force F_r was assumed to be equal to the force at which the friction force has been overcome and implant motion has begun in relation to the elastomeric membrane. Additionally, during the tests it should be known whether the large number of cycles cause any damage, e.g. cracking of the membrane.

3. Research results

The results obtained owing to the application of titanium counter specimens subjected to sandblasting with a 350 μm abrasive and a membrane made of Molloplast B are compiled in table 1. The loss in retention force resulting from an increasing number of cycles for an attachment using an implant of a 2.65 mm diameter is presented in figure 5. In the

Table 1. Results of fatigue tests of attachments:
Molloplast B – implant sandblasted with abrasive of 350 μm

Number of cycles	Diameter of implant sandblasted with abrasive of 350 μm			
	2.65 mm		2.85 mm	
	F_r [N]	u_{max} [mm]	F_r [N]	u_{max} [mm]
0	3.96 ± 0.08	0.62 ± 0.02	6.54 ± 0.24	1.17 ± 0.07
200	3.9 ± 0.04	0.61 ± 0.02	6.49 ± 0.18	1.25 ± 0.04
400	3.93 ± 0.06	0.59 ± 0.02	6.49 ± 0.11	1.28 ± 0.04
800	3.86 ± 0.06	0.55 ± 0.01	6.54 ± 0.14	1.24 ± 0.04
1,200	3.8 ± 0.06	0.57 ± 0.02	6.29 ± 0.13	1.26 ± 0.05
1,600	3.62 ± 0.06	0.54 ± 0.02	5.8 ± 0.14	1.19 ± 0.03
2,000	3.48 ± 0.08	0.53 ± 0.02	5.63 ± 0.15	1.12 ± 0.04
2,400	3.24 ± 0.08	0.50 ± 0.02	5.41 ± 0.13	1.07 ± 0.03
3,000	2.98 ± 0.1	0.44 ± 0.02	5.16 ± 0.13	0.98 ± 0.06
4,000	2.89 ± 0.07	0.39 ± 0.02	4.72 ± 0.12	0.91 ± 0.04
5,000	2.82 ± 0.07	0.37 ± 0.01	4.6 ± 0.14	0.86 ± 0.05
6,000	2.73 ± 0.1	0.36 ± 0.01	4.34 ± 0.11	0.81 ± 0.04
7,500	2.67 ± 0.08	0.35 ± 0.01	4.03 ± 0.12	0.76 ± 0.03
9,000	2.67 ± 0.06	0.36 ± 0.01	3.94 ± 0.12	0.7 ± 0.03
10,000	2.62 ± 0.08	0.33 ± 0.01	3.8 ± 0.11	0.65 ± 0.03

initial period, the loss in the value measured was insignificant and after 1,200 cycles, the retention force decreased by 4% only. Subsequent 1,200 cycles, corresponding to another 6-month period, caused an 18% decrease of F_r in relation to the initial value. After 5,000 cycles, F_r was reduced by further 11%; however, the subsequent decrease was insignificant, with the loss after 10,000 cycles amounting to 34%, and F_r of 2.62 N. For the titanium counter specimen of a diameter of 2.85 mm, the decrease in F_r after 1,200 cycles was 4%. Next, the retention force decreased slightly faster (figure 6). There is no clear stabilization of the force measured and after 10,000 cycles, it achieves a value equal to 3.8 N, which accounts for 67% of the initial value.

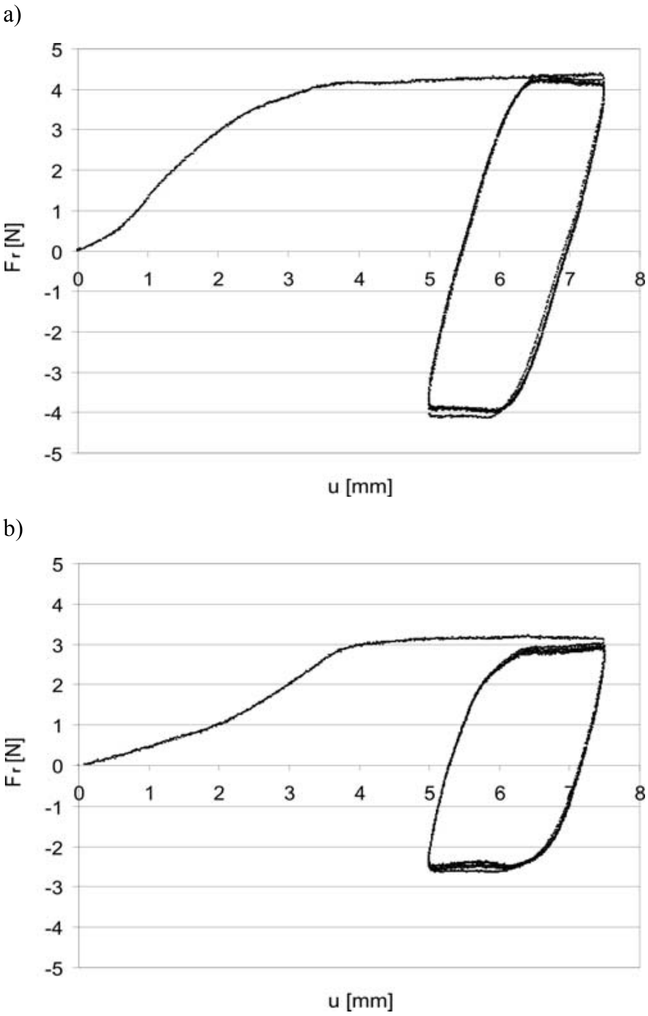

Fig. 5. Examples of characteristics of attachments for implants of a 2.65 mm diameter sandblasted with 500 μm abrasive: a) a new elastomeric membrane and b) after 10,000 cycles

The results obtained for the titanium counter specimens subjected to sandblasting with a 500 μm abrasive and a membrane made of Molloplast B are compiled in table 2. The first 1,200 cycles caused a 4% decrease in F_r for both implants with a diameter equal to 2.65 mm and 2.85 mm (figure 7). For counter specimens of 2.65 mm in diameter, the retention force after 2,000 cycles begins to drop a little more rapidly and stabilizes after 4,000 cycles at a level of 3.2 N. After 10,000 cycles, F_r achieves an average value of 2.93 N, accounting for 71% of the initial value. In the case of the implant of 2.85 mm in diameter, a more rapid decrease of F_r begins after 1,200 cycles and achieves considerable values to 10,000 cycles, after which F_r amounts to 3.9 N, which makes up to 57% of the initial value. Although a supposition can be made that an increasing number of cycles result in a further loss in the retention force, from the point of view of the intended purpose, this fact should be regarded as insignificant.

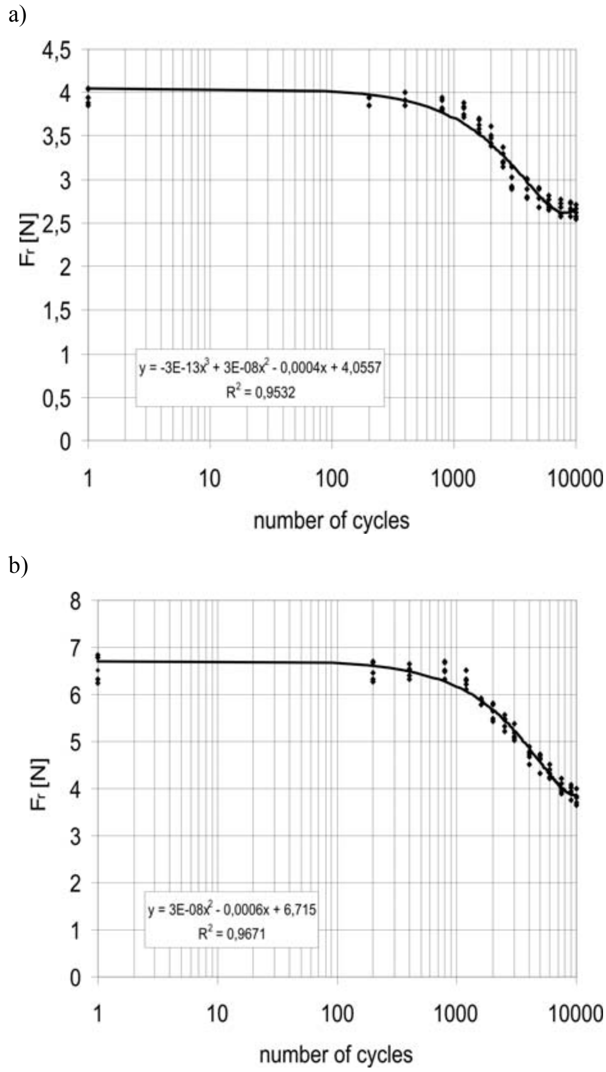

Fig. 6. Influence of the number of cycles on retention force value for Molloplast B – implant attachment: a) 2.65 mm diameter implant sandblasted with a 350 μm abrasive, b) 2.85 mm diameter implant sandblasted with a 350 μm abrasive

Table 2. Results of fatigue tests of attachements:
Molloplast B–implant sandblasted with abrasive of 500 μm

Number of cycles	Diameter of implant sandblasted with abrasive of 500 μm			
	2.65 mm		2.85 mm	
	F_r [N]	$u_{\max}$ [mm]	F_r [N]	$u_{\max}$ [mm]
0	4.14 ± 0.07	0.68 ± 0.04	6.87 ± 0.17	1.35 ± 0.07
200	4.08 ± 0.08	0.69 ± 0.05	6.86 ± 0.1	1.32 ± 0.05
400	4.02 ± 0.11	0.68 ± 0.03	6.80 ± 0.11	1.34 ± 0.08
800	4.02 ± 0.1	0.67 ± 0.01	6.74 ± 0.12	1.32 ± 0.08
1,200	3.99 ± 0.09	0.66 ± 0.01	6.60 ± 0.15	1.28 ± 0.06
1,600	3.90 ± 0.05	0.64 ± 0.01	6.31 ± 0.13	1.24 ± 0.05
2,000	3.80 ± 0.05	0.59 ± 0.02	6.02 ± 0.11	1.17 ± 0.06
2,400	3.60 ± 0.05	0.63 ± 0.03	5.60 ± 0.15	1.11 ± 0.08
3,000	3.40 ± 0.04	0.59 ± 0.01	5.36 ± 0.08	1.05 ± 0.04
4,000	3.20 ± 0.04	0.59 ± 0.01	4.90 ± 0.09	1.04 ± 0.03
5,000	3.11 ± 0.03	0.54 ± 0.01	4.67 ± 0.1	0.93 ± 0.04
6,000	3.08 ± 0.04	0.53 ± 0.01	4.37 ± 0.06	0.89 ± 0.04
7,500	3.03 ± 0.04	0.52 ± 0.02	4.18 ± 0.09	0.85 ± 0.03
9,000	2.96 ± 0.05	0.57 ± 0.03	4.07 ± 0.09	0.83 ± 0.03
10,000	2.93 ± 0.06	0.50 ± 0.02	3.95 ± 0.08	0.73 ± 0.05

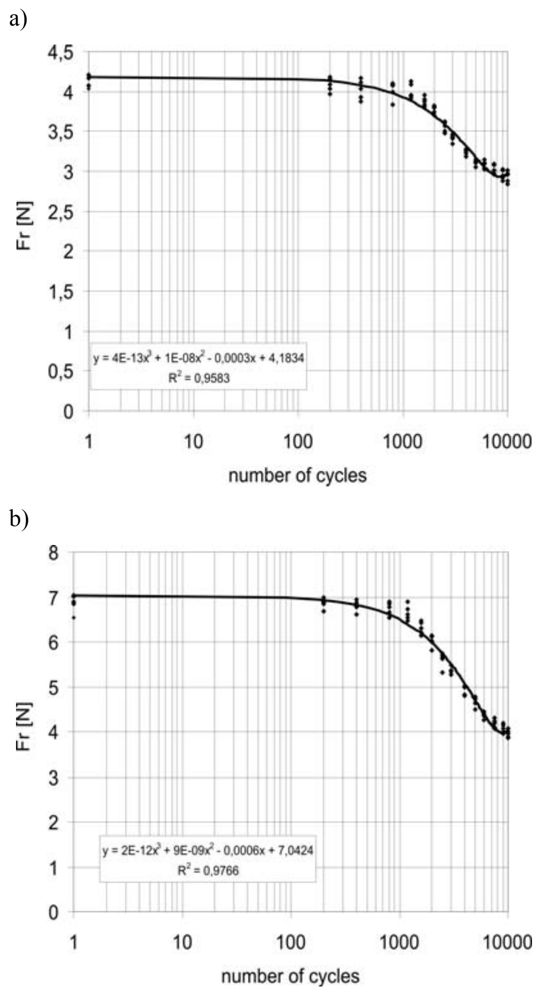

Fig. 7. Influence of the number of cycles on retention force value for Molloplast B–implant attachment: a) 2.65 mm diameter implant sandblasted with a 350 μm abrasive, b) 2.85 mm diameter implant sandblasted with a 350 μm abrasive

4. Summary and conclusions

Polymer materials, such as Molloplast B, are commonly used in dental prosthetics for denture lining. This paper shows a new area of applying such materials. Due to their original use, there have been no studies conducted so far that would allow evaluating tribological wear of such polymers juxtaposed with a hard substrate.

The evaluation of the influence of an attachment's operation time on the retention force values has shown that all of the titanium–elastomer couples tested are characterized by the durability sufficient to allow correct functioning of the attachment for at least six months. Further using of attachments leads to a systematic reduction of the retention force. It should be emphasized that usually at least two implants are used to stabilize complete dentures of the type described, which means that the achieved in situ retention forces on the implants themselves will be two times higher than those determined. Based on the research performed, the following conclusions have been formulated:

1. The solution proposed ensures practically stable conditions of denture retention on the base for six months.

2. After a working life eight times longer than originally assumed, the decrease in retention force does not exceed 43%.

3. An increase in the retention force through increasing the diameter of a titanium counter specimen results in the intensive wear of the elastomeric membrane.

4. In none of the tested attachments have cracks or mechanical damage been observed, which could cause the slipping of the elastomeric membrane out of its seating, thus posing danger to the patient.

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