Acta of Bioengineering and Biomechanics
Vol. 12, No. 3, 2010

Original paper

The evaluation of selected attachment systems for implant-retained overdenture based on retention characteristics analysis

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The results of mechanical characteristics of attachments used for retaining and stabilizing overdenture have been analysed. Two commercially used attachments (a ball attachment and a bar attachment) and elastic frictional attachments designed by the research team with Professor Chladek as the leader have been investigated. The diagrams of force–displacement characteristics have been registered. Retention forces (F_R) have been determined and total work (W_T) disconnecting the attachments has been calculated on the basis of these diagrams. The analysis of total work corresponding to different types of attachments made it possible to distinguish some characteristic areas which illustrate specific features of particular designs.

It has been revealed that determining the retention force allows us to compare only the attachments which work on similar bases. In order to conduct a purely objective comparison of the efficiency of different designs, it is necessary to analyze complete force–displacement characteristics as well as to determine on this basis the subsequent phases of separating the parts of attachments and to find the value of the work which in fact determines their quality. The comparison of selected commercially used designs and the presented elastic frictional attachments (taking into account the criterion of work) gives clear evidence that the introduced design of attachment enables us to create very good conditions of retaining overdenture.

Key words: *retention, overdenture, force, work, implant, denture, attachment, mechanical characteristic*

1. Introduction

Commercially offered systems of attaching overdenture were very efficient initially, but when they were used for a long period of time it was not possible to avoid some problems posed by the athrophy of alveolar ridge. Attachments with shock-absorbing buffer [1] are not sufficient if the process of athrophy is quite advanced. In such cases, the buffer is not able to deform and the denture needs to be rebased. Introducing the elastic frictional attachment designed by research team of Professor Chladek seems to be reasonable since it has a direct contact with the integrated abutment (IA) or abutment [2]. The principle of the functioning of the attachment is presented in figure 1. It assumes that the retention element (matrix) is an integral part of a soft liner of an ordinary acryl denture. Retention is guaranteed by a hole in a soft liner which is undersized to the diameter of IA. This allows us to form insertion which generates an implant–silicone rubber frictional connection. Adequately chosen geometry and specific material properties of silicone enable the process of elastic strain of the element in accordance with the resilience of mucosa in the bearing area. A hole milled in acrylic denture facilitates the use of elastic properties of silicone rubber very effectively and therefore it reduces the load of both

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Received: February 22nd, 2010
Accepted for publication: July 15th, 2010

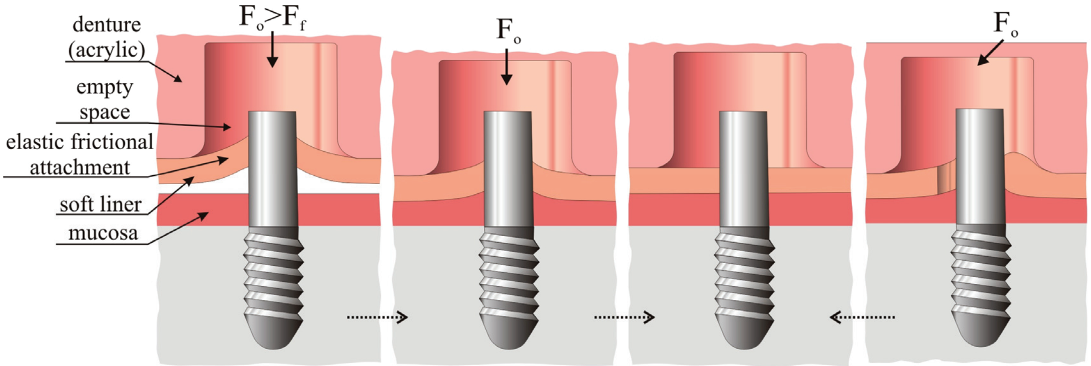

Fig. 1. Structure and operation of elastic frictional attachment with conceptual presentation of reactions at different types of the load applied

implant and tissues around the implant [2]. Such an attachment mainly stabilizes the denture, whereas the occlusion forces are transferred mostly by the denture base to the tissues of the bearing area. Uniformly loaded bearing area ought to slow down the atrophy of the alveolar ridge [3]–[6] and to prevent some possible damage to dentures and overloaded implants [3]–[8]. This solution has the added advantage of adjusting that denture to the existing height of the alveolar ridge (in the case of athrophy) or to the thickness of mucosa and therefore rebasing is not necessary. Such an effect can be achieved when friction forces between the elements of the attachment, the stiffness of elastic element (rubber) and the resilience of the bearing area are correctly selected [2]–[9]. Laboratory tests gave clear evidence that mechanical durability of elastic frictional attachments is sufficient to guarantee their proper functioning even for four years [10]–[11].

The attachment made according to our design works in different way than those applied in bar attachments and ball attachments. The two latter ones can only make a stiff connection between denture and pillar. A design with bar attachments can be a good example to illustrate that any turn related to the axis of a bar pulls out the clips put on a bar which causes immediate removal of a denture. Such a turn, for example, can be made by a denture in the area of molar teeth by a slight movement of tongue or when the denture is strained excessively in the area of incisors. This will not happen when elastic attachments are applied, because an elastic material used, i.e. silicone rubber, gives a chance of keeping their considerable ability of reversible strain both at side and vertical movements of a denture and when it moves along the axis of integrated abutment at work (figure 1). Therefore the measurements of retention forces cannot be a reliable criterion for comparing such diverse retention elements because that criterion does not take into consideration the force–displacement characteristics but only the instantaneous mechanical state of attachment. The objective verification of the effectiveness of different types of connections is possible only if the characteristics have been analyzed and other criterion has been introduced. Such a criterion should take into account both measured physical quantities because they influence the quality of the attachments. The work, which ought to be done in order to separate the attachment, seems to be the best criterion.

2. Material and methods

The investigations of retention characteristics of attachments have been carried out on the Zwick testing machine. Two types of commercially used attachments have been applied in the first stage of examinations:

- ball attachment with a ball of 2.5-mm diameter with a plastic clip (figure 2a),
- bar attachment – a bar of 1-mm wide base with a head of 1.8-mm diameter and a plastic clip (figure 2b).

All the elements of the attachments have been seated on acrylic base and fixed to a duralumin flat bar so that they could be fastened tightly in the jaws of a tester.

In order to investigate the retention characteristics of elastic frictional attachments, a special holder for fixing the tested samples and carrying out the tests has been designed (figure 3). The holder enables us to keep the alignment of force which expands the attachment. The impact of the saliva introduced between the interacting surfaces is essential for monitoring friction forces when the frictional elements (IA and silicone rubber) have been attached [9]. Therefore, a special holder has been equipped with a chamber filled with artificial saliva. Implant models with endings which simulated integrated abutments (IA) of

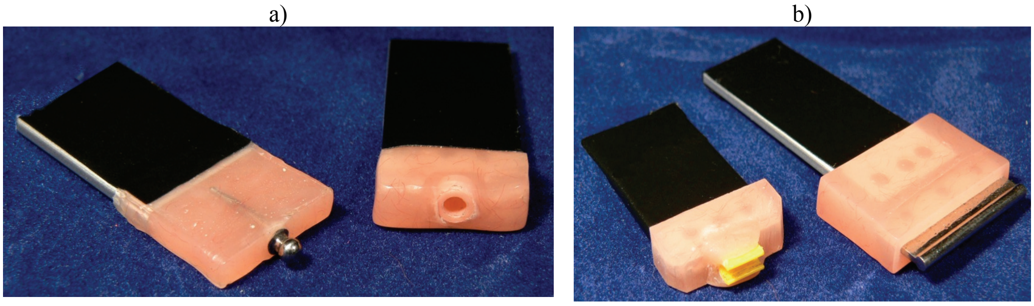

Fig. 2. Samples for investigating retention forces of commercially used attachments: attachment with a ball of 2.5-mm diameter (a) and attachment with a plastic clip (b)

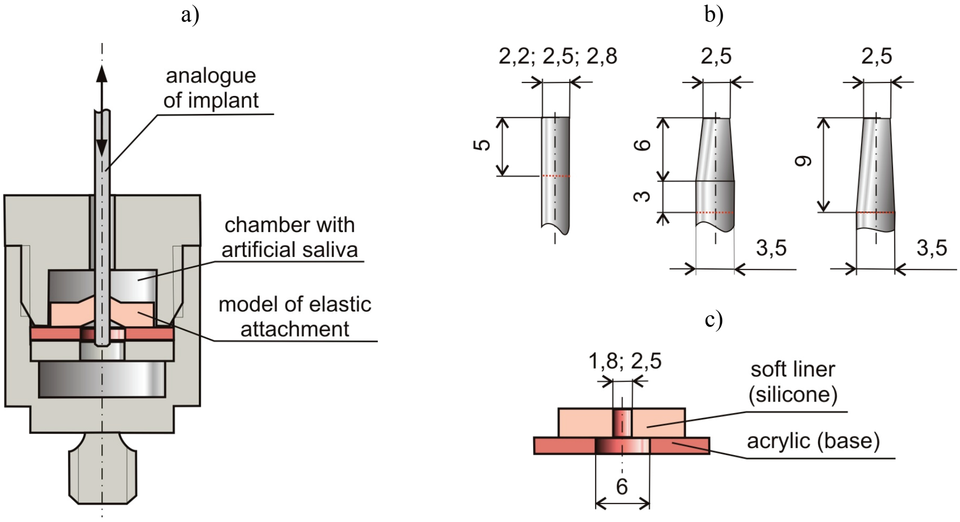

Fig. 3. Holder for investigating retention characteristic of elastic frictional attachments (a), geometry and essential dimensions of samples which simulate one-stage implants (b) and geometry with dimensions of elastic element models (c)

Table 1. Chemical composition of Ti6A14V alloy used for making analogues

Element:	Al	V	Cr	Fe	Si	Ni	C
% mass	5.85	3.34	0.01	0.17	0.02	0.01	0.02

selected implants, i.e. Garbaccio, Q-Implant, Alpha-Bio, have been used in the tests. Technical criteria such as cylindrical or conical shapes of IA, easy and stable way of placing them in the attachment, single-stage surgical procedure implants have been taken into consideration while choosing the implants tested. The economic aspects have also been taken into account because the suggested design should be relatively cheap. Six analogues of different diameters and geometry of a part corresponding to IA of the real implant have been made after a thorough analysis of geometric features of implants (figure 3b):

- Analogues of cylindrical geometry of integrated abutment (CIA), $\phi = 2.2$ mm, $\phi = 2.5$ mm, $\phi = 2.8$ mm.
- Analogue of cylindrical-conical geometry of integrated abutment (CCOIA),
- Analogue of conical geometry of integrated abutment (COIA).

All the samples in a frictional attachment simulating implants have been made of Ti6A14V titanium alloy and their surfaces have been polished. Chemical composition of the alloy used is presented in table 1.

The analogues of elastic retention element have been made of Molloplast B silicone material joined with acrylic base (figure 3c). Before silicone has been put in, a hole of 6-mm diameter was made in the middle of acrylic part in order to enable the "membrane" to deflect during the tests. A silicone layer was of the same thickness in all the samples (2.5 mm). A hole which was centric and undersized to the diameter of IA has been made in the models; its diameter was:

- 1.8 mm – for CIA type of analogues,
- 2.5 mm – for COIA or CCOIA type of analogues.

An example of retention characteristics for commercially used attachment is presented in figure 4a. New attachments were connected and disconnected fifteen times before the tests began [12]. The attachments were expanded in the tests and the changes of force in the function of displacement while moving up the retention element were registered. The cycle velocity was 5 mm/min. The test was carried out five times for each type of attachment, and a mean value of the retention force (F_R) was calculated. The maximal value of the force was assumed to be F_R.

During the tests with elastic frictional attachments, both the force generated while the titanium sample was moved in the attachment and its displacement have been registered. Close attention has been paid to the axial position of analogue against the hole in a silicone rubber to obtain the reliable and repeatable results. The cycle velocity was 15 mm/min. An example of a full mechanical characteristics together with the presentation of a concept of particular stages of work of the attachment is presented in figure 4b. Four initial cycles of 2.5-mm displacement have been made in each test after the first stage when the model of implant was placed in the hole. This ensured the stability of attachment and provided stress relaxation of the compressed silicone rubber [13]. During the fifth cycle a titanium sample was taken out from the membrane (it came back to its initial position).

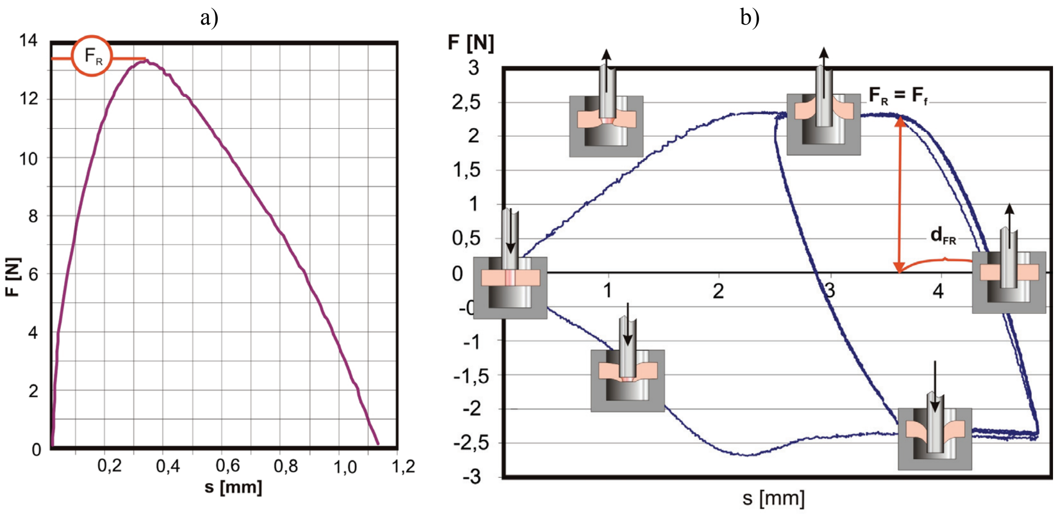

Fig. 4. Example of retention characteristic of a ball attachment (a) and complete mechanical characteristic for a model of elastic frictional attachment using the analogue of CIA type (ϕ = 2.2 mm) with conceptual presentation of analogue movements in the attachment (b)

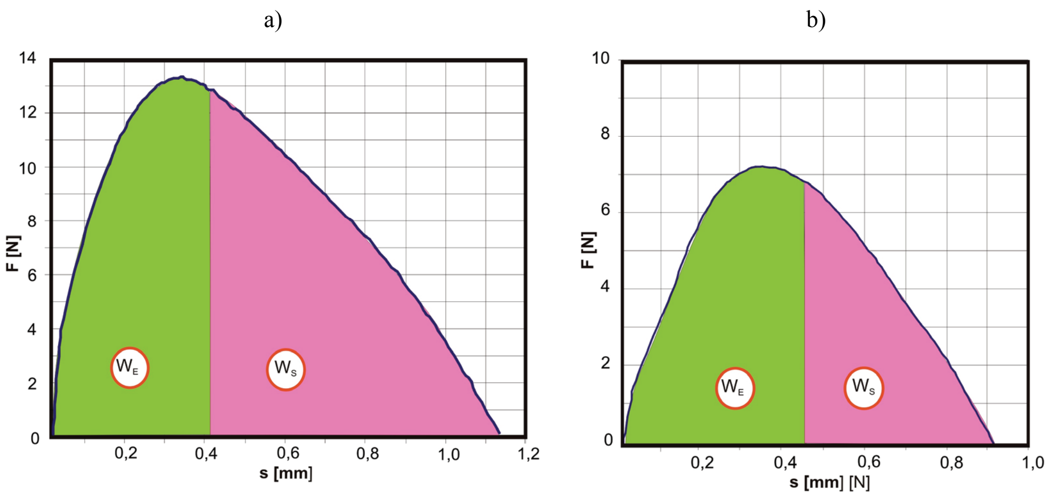

Fig. 5. Example of retention characteristics for a ball attachment (a) and bar attachment with a polymer clip (b) with marked areas of W_E and W_S

Part of the last cycle, starting from the position of equilibrium (F = 0 N) until all the interacting elements were separated, was assumed to be the retention characteristics of the attachment in the analysis carried out. Such a presentation of retention characteristics corresponds to the actual functioning of the retention element, while the implant is being removed by the force parallel to the IA-axis, as it is in the case of measurements carried out for commercial attachments. The F_R of the attachments examined is that force registered which causes maximal deflection (d_{FR}) of the elastic membrane; in that moment the friction force (F_F) is overcome and the movement of the analogue against the elastomeric membrane begins (figure 4b).

The results obtained have been read in the calculation sheet. The areas under the curves have been calculated and thus the work essential for separating the attachments has been determined. While analyzing the characteristics, a total work (W_T) done by different types of the attachments has been divided, depending on particular types of their design. The distinguished areas are responsible for the effectiveness of attachments. W_T for a ball attachment and a bar attachment has been divided into two basic areas (figure 5):

- The area W_E – effective work of the attachment. In this part of retention characteristic, the attachment transfers the load in an effective way. At the first stage, an automatic return of the retention element to the initial position is possible after the load has been removed, whereas in the second stage (after F_R has been exceeded), the return can be caused by applying slight force; the attachment is stabilized.
- The area W_S – separation work; the area of the instability of attachment. In real conditions, there is "automatic" separation, because the elasticity force of the retention element is greater than friction force responsible for the retention of attachment and that is why a bar or a ball is pushed out of the retention element and so the pace of the process helps the patient to react.

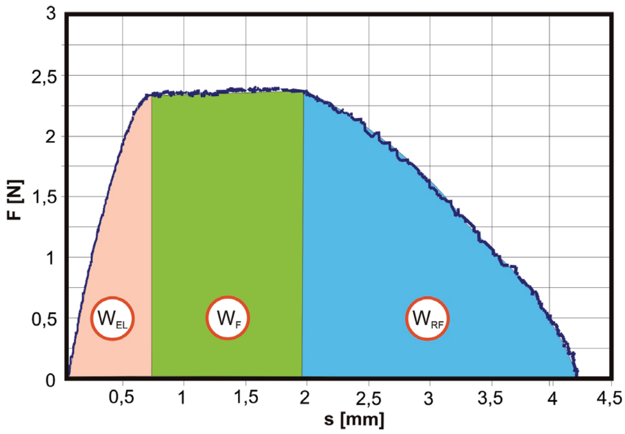

Fig. 6. Example of retention characteristic for elastic frictional attachment using CIA, ϕ = 2.2-mm analogue with marked areas of W_{EL}, W_F, W_{RF}

The work W_T for the elastic frictional attachments has been divided into the following characteristic areas (figures 6 and 7):

- The area W_{EL} – the work of elastic strain of the retention element. In this part of retention characteristics, IA does not move against the elastic attachment and when load has been removed the attachment "automatically" returns to its initial position.

a) b)

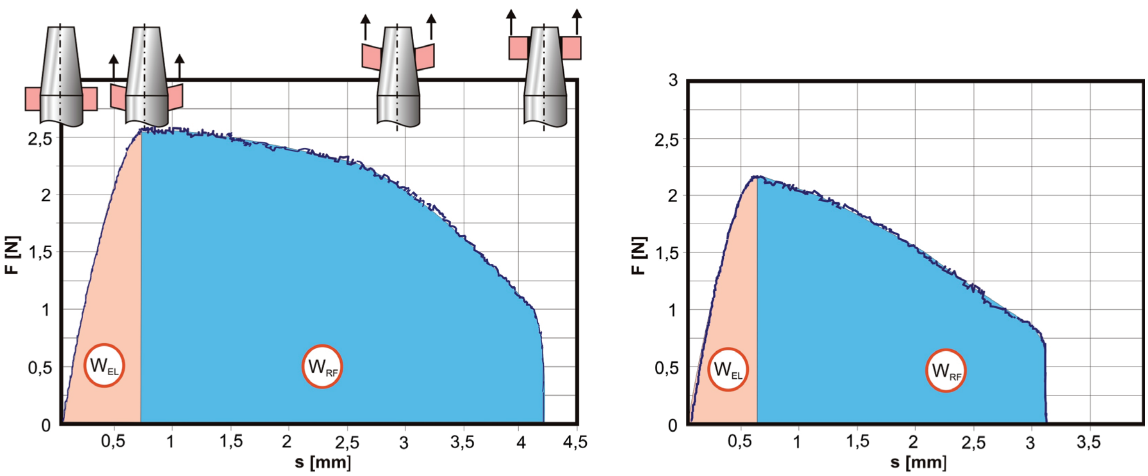

Fig. 7. Example of retention characteristics for elastic frictional attachments using CCOIA (a) and COIA (b) analogues with marked areas of W_{EL} and W_{FR}

• The area W_F – friction work, determined when the analogues of CIA type are applied. When friction force has been overcome, then a titanium sample moves against the retention element (in real conditions, the retention element together with the denture moves against IA), the surface of the real contact of IA with silicone rubber does not decrease, a return to the initial position can occur but not automatically, only if the force applied acts in opposite direction and exceeds the value of friction force.

• The area W_{RF} – a remaining friction work. The analogue moves against the retention element, in CCOIA and COIA analogues the size of insertion decreases (figure 7), the surface of the real contact between IA and silicone rubber decreases because the sample moves out from the attachment, a return to the initial position is still possible after applying force greater than friction force.

3. Results

In the tests carried out, the highest average value of F_R, i.e. 13.34 N, has been registered for a ball attachment with a ball of 2.5-mm diameter. The average value of F_R was 7.23 N for the bar attachment with a polymer clip as the retention element. The results are listed in table 2.

Table 2. Average values of retention forces with standard deviations for commercially used attachments

Force	Types of attachment	
	Ball attachment	Bar attachment
F_R (N)	13.34±0.31	7.23±0.25

The values of calculated W_T and its components are presented in table 3. The highest value of W_E, regarding the part of characteristics which is responsible for effective functioning of the attachment, is 4.05 mJ and it has been obtained for a ball attachment. The value of W_E equals 2.67 mJ for a bar attachment. These results show similar effectiveness of the tested attachments as F_R values investigations did.

Based on the tests carried out on the analogues of elastic frictional attachments it has been indicated that for analogues of CIA type, the average values of F_R slightly increased with the increase in the implant diameter within the range of 2.2 N–2.63 N. The results have been presented in table 4. Quite similar results (table 5) have been obtained for the models of COIA and CCOIA attachments – 2.6 N and 2.18 N, respectively. In all cases, the F_R values obtained were significantly lower than those of traditional designs.

The mean values of a total work done by elastic frictional attachments ranged from 4.46 mJ in the least favourable design with applied analogue of COIA type to 8.99 mJ when we dealt with the analogue of CIA type and the biggest diameter. An accurate presentation of the results obtained is given in tables 4 and 5.

Table 3. Average value of retention works with standard deviations for selected commercially used attachments

Types of attachment	$W_E \times 10^{-3}$ (J)	$W_S \times 10^{-3}$ (J)	$W_T \times 10^{-3}$ (J)
Ball attachment	4.05±0.1	5.38±0.09	9.43±0.11
Bar attachment	2.67±0.06	1.41±0.08	4.08±0.08

Table 4. Average values of retention forces and retention work with standard deviations for the elastic frictional attachments with analogues of CIA type

Diameter of IA (mm)	F_R (N)	W_{EL} $\times 10^{-3}$ (J)	W_F $\times 10^{-3}$ (J)	W_{RF} $\times 10^{-3}$ (J)	W_T $\times 10^{-3}$ (J)
2.2	2.2±0.06	1.03±0.05	3.68±0.09	2.89±0.06	7.59±0.09
2.5	2.42±0.09	1.44±0.06	3.76±0.1	2.92±0.08	8,12±0.13
2.8	2.63±0.08	1.75±0.05	4.13±0.12	3.11±0.09	8.99±0.2

Table 5. Average values of retention forces and retention work with standard deviations for the elastic frictional attachments with analogues of CIA type

Analogue	F_R (N)	W_{EL} $\times 10^{-3}$ (J)	W_{RF} $\times 10^{-3}$ (J)	W_T $\times 10^{-3}$ (J)
CCOIA	2.6±0.13	1.11±0.11	7.60±0.17	8.71±0.16
COIA	2.18±0.15	0.73±0.06	3.73±0.14	4.46±0.22

4. Discussion

The measurements of retention forces of commercially used implant attachments are usually carried out simultaneously with durability tests in vitro. According to [14] the value of F_R equal to 15.3 N was reached in new bar attachments with two metal clips and F_R was 13.7 N when two plastic clips were used. The retention force of a bar attachment with a single cast clip holder measured and presented in paper [12] approached 25.2 N for the new attachment, whereas for the "stabilized" one (after fifteen separations) it was 8.6 N. Six commercially used ball attachments were tested and the results within the range of 8.2 N–14.0 N are presented in paper [15]. Similar values of F_R were reached during in vitro tests of dentures with bar attachments (32.9 N ± 9.1 N) or with ball attachments (31.4 N ± 8.3 N) [16].These results correspond to the results presented in this paper for commercially used designs. However, F_R values for elastic frictional attachments were few times lower and this can be clearly seen in figure 8a. A phenomenon of a gradual decreasing of the registered force while the analogue moves against the elastic element can be noticed when CCOIA and COIA analogues have been used in elastic attachments (figure 7). Such an effect results from the fact that the insertion is getting smaller until the last phase of the cycle is ended up with a sudden loss of stability of the attachment. This happens when the elastic element "separates" from the conical part of a model. The method of F_R measurement applied in investigations, like most results of measurements presented in technical literature, is based on the measurements of maximal force which disconnects the attachment and acts in the direction which is in accordance with the axis of implant [17]–[22]. The methods of measurements based on a defined angle are less frequently used [23]–[24]. Although there are some methodological differences, such research methodology gives a chance of comparing the attachments of similar character which operate in a similar way. However, the displacements of particular elements of the attachment against one another before it loses its stability are very rarely considered in the discussion of investigation results [25]. So far there have been no papers regarding that problem which is also important as far as the quality of the attachments is concerned. The traditionally applied designs such as bar and ball attachments feature "stiff" mechanical characteristics, i.e. at reasonably high retention force, the relative displacement of matrix and patrix before the attachment is separated is very small. The analysis of characteristics presented in figure 5 reveals that even the slightest (0.4–0.5 mm) vertical displacement of a clip results in the loss of stability of the attachment. That is why F_R is a good criterion to compare these types of attachments relatively well. However, it should be remembered that it is a considerable simplification since a real mechanical characteristics is not taken into account. A figurative comparison can illustrate the problem of applying F_R as a criterion for the evaluation of attachments with different mechanical characteristic. If we say that making twenty or forty steps while carrying 10 bottles of water is exactly the same activity because in each of the cases the same force must be used for lifting the bottles, everyone knows that it is false. Yet it is true that it is more difficult to carry 15 bottles covering the distance of 18 steps than carrying 10 bottles covering the distance of 20 steps. Exactly the same applies when assessing the implant attachments. The actual effectiveness of the attachment depends not only on retention force but also on the distance covered by retention elements against one another before they lose stability. As far as the elastic attachments featuring "soft" characteristics are concerned, vertical movement, essential for separating the connections, ranged from 3 mm to about 4.5 mm (figures 6 and 7) which is six to eleven times more than in commercially used designs. That is why an objective comparison of attachments with one another can be possible only after mechanical characteristics have been analyzed and both most important parameters have been considered. It can be done by calculating the areas under the curves. The calculated work gives information on how much energy is necessary to separate the attachment. The interpretation of the results obtained is made possible by dividing the diagrams of displacement–force characteristics into the areas related to their instantaneous mechanical state by distinguishing the types of work responsible for effective and stabilized functioning of the elements analyzed: W_E for traditional attachments and W_T for elastic frictional attachments. A summarizing list of compared values for the examined attachments has been presented in figure 8b. The values of W_T of the elastic attachments approximated the values of W_T obtained for commercial attachments and they were higher than the values of W_E work responsible for functioning the traditional designs. On the basis of this criterion it can be seen that despite the fact that retention forces are lower in elastic attachments, yet the attachments are more difficult to pull apart. Specific properties of silicone rubber such as high elasticity and small values of friction forces between rubber and the implant in

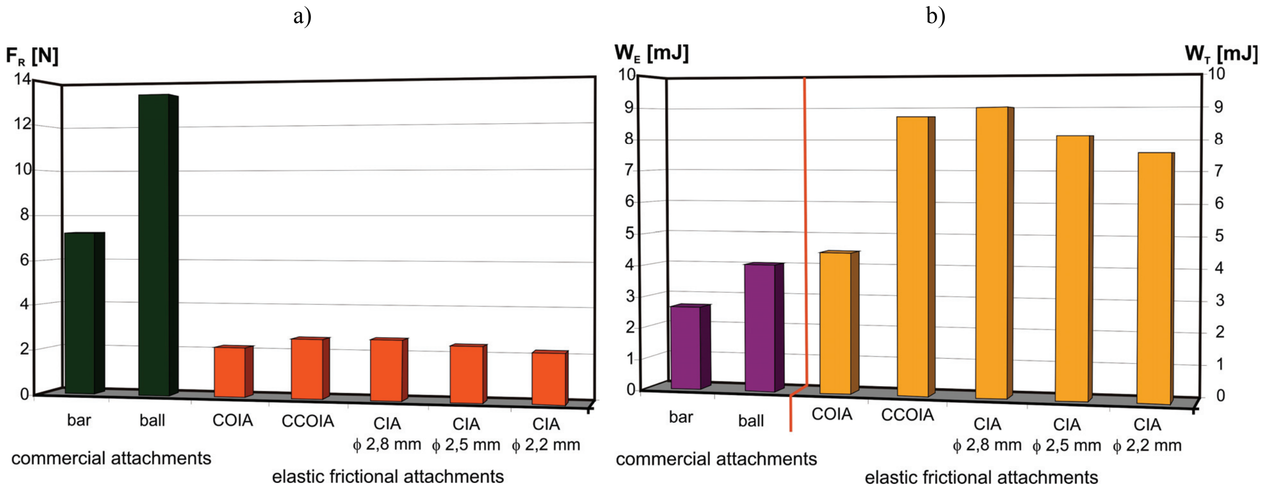

Fig. 8. A comparison of the average value of retention forces (a) and W_E with W_T (b) for the types of attachments examined

attachments of that type with considerably extended distance necessary for separating the attachment (movement of a silicone attachment against the implant) allow us to consider the whole area of characteristics as the area of effective functioning. Even in that part of the area where friction forces begin to decrease, the loss of stability cannot start automatically without making a decisive move. Removing load will result in regaining a part of energy of the attachment just like in spring reaction (W_S work), whereas the application of force (in opposite direction) larger than friction force will cause a return of the attachment to the initial position. Comparable results of the investigations of traditional attachments have been obtained only for the analogues of COIA type for which the distance of friction is short due to geometry of the analogue. Even in that case the value of W_T was about 9% higher compared to the value of W_E obtained for the best quality commercial attachment available. It should be noticed that even a slight extension (about 1 mm) of cylindrical IA fragments which interact actively with silicone rubber could facilitate 20–30% increase of the value of W_T, due to the process of "expansion" of the most effective parts of characteristics with W_F. A slight sensitivity of F_R and W_T registered in analogues of CIA type to the size of the insertion (undersize of a hole in the rubber sample to the diameter of IA) can be explained by the character of friction phenomena in the attachment. The conditions are as follows: artificial saliva trapped in silicone rubber irregularities has been introduced between two interacting surfaces and this makes a film on the surface of the implant. As a result, artificial saliva is a kind of lubricant which cannot come out of the system [26]–[27] and this allows us to enlarge the surface of real contact together with the increased value of the force of pressure activated by the inserted part. Thus, the value of the friction force F_R registered does not increase either.

5. Conclusions

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

1. The new type of evaluating the effectiveness of implant attachments which is based on determining and analyzing the successive phases of total work of the attachment allows us to carry out an objective comparison of different designs of attachments for overdenture.

2. A comparison carried out on the basis of the determined retention work in traditional attachments and elastic frictional attachments gave evidence that the suggested type of attachment makes it possible to obtain very good conditions of retaining the overdenture.

3. The extended IA part actively interacting in elastic frictional attachment is very advantageous for cylindrical geometry because it allows us to enlarge the most effective area of W_F characteristics.

4. Expanding the undersize of the diameter of a hole in the retention element in relation to IA diameter so as to increase the value of acting force exerted by the attachment upon IA only slightly results in the increase of the effectiveness of elastic frictional attachments. The main cause of this is the character of the types of friction in the attachment.

5. Retention force is a simplified criterion which enables us to compare with one another the attach-

ments which feature alike stiff mechanical characteristics in an easy way.

Acknowledgements

This study was supported by the Ministry of Science and Higher Education, research project N N518 425836.

References

[1] Bredent – products for the dental-technical laboratory, 2005.

[2] CHLADEK W., CHLADEK G., LIPSKI T., MARGIELEWICZ J., ŻMUDZKI J., *Biomechanical problems related to design of implantological overdenture stabilization system* (in Polish) , Wydawnictwo Politechniki Śląskiej, Gliwice, 2008.

[3] QUIRYNEN M., NAERT I., Van STEENBERGHE D., *Fixture design and overload influence marginal bone loss and fixture success in the Brånemark® system*, Clin. Oral Impl. Res., 1992, 3, 104–111.

[4] MACENTEE M.I., WALTON J.N., GLICK N., *A clinical trial of patient satisfaction and prosthodontic needs with ball and bar attachments for implant-retained complete overdentures: Three-year results*, J. Prosthet. Dent., 2005, 93, 28–37.

[5] WALTON J.N., HUIZINGA S.C., PECK C.C., *Implant angulation: a measurement technique, implant overdenture maintenance, and the influence of surgical experience*, Int. J. Prosthodont., 2001, 14, 523–30.

[6] NAERT E., HOOGHE M., QUIRYNEN M., Van STEENBERGHE D., *The reliability of implant-retained hinging overdentures for the fully edentulous mandible. An up to 9-year longitudinal study*, Clin. Oral Invest., 1997, 1, 119–124.

[7] WATSON G.K., PAYNE A.G., PURTON D.G., THOMSON W.M., *Mandibular overdentures: comparative evaluation of prosthodontic maintenance of three different implant systems during the first year of service*, Int. J. Prosthodont., 2002, 15, 259–66.

[8] BEHR M., LANG R., LEIBROOK A., ROSENTRITT M., HANDEL G., *Complication rate with prosthodontic reconstructions on ITI and IMZ dental implants*, Clin. Oral. Impl. Res., 1998, 9, 51–8.

[9] CHLADEK W., HADASIK E., CHLADEK G., *Influence of surface modification on friction coefficient of the titanium–elastomer couple*, Acta of Bioengineering and Biomechanics, 2007, Vol. 9, No. 2.

[10] CHLADEK G., *Durability evaluation of a friction couple intended for implantological stabilization of complete dentures*, Acta of Bioengineering and Biomechanics, 2008, Vol. 10, No. 3.

[11] CHLADEK G., *Influence of tribological wear on the effectiveness of the new type implantological attachment* (in Polish), Inżynieria Materiałowa, styczeń–luty 2009, Nr 1 (167).

[12] BREEDING L., DIXON D., SCHMITT S., *The effect of simulated function on the retention of bar-clip retained removable prostheses*, The Journal of Prosthetic Dentistry, 1996 May, 75(5), 570–573.

[13] CHLADEK G., KRAWCZYK C., *Investigation of viscoelasticity of silicone rubber samples* (in Polish), Nowoczesny Technik Dentystyczny – wydanie specjalne, Katowice, 2007.

[14] WALTON J.N., RUSE N.D., *In vitro changes in clips and bars used to retain implant overdentures*, J Prosthet. Dent., 1995 Nov, 74(5), 482.

[15] WOLF K., LUDWIG K., HARTFIL H., KERN M., *Analysis of retention and wear of ball attachments*, Quintessence Int., 2009 May, 40(5), 405–412.

[16] van KAMPEN F., CUNE M., van der BILT A., BOSMAN F., *Retention and postinsertion maintenance of bar-clip, ball and magnet attachments in mandibular implant overdenture treatment: an in vivo comparison after 3 months of function*, Clin. Oral Implants Res., 2003 Dec, 14(6), 720–726.

[17] SADIG W., *A comparative in vitro study on the retention and stability of implant-supported overdentures*, Quintessence Int., 2009 Apr, 40(4), 313–319.

[18] BESIMO C.E., GUARNERI A., *In vitro retention force changes of prefabricated attachments for overdentures*, J. Oral. Rehabil., 2003 Jul, 30(7), 671–678.

[19] BOTEGA D.M., MESQUITA M.F., HENRIQUES G.E., VAZ L.G., *Retention force and fatigue strength of overdenture attachment systems*, J. Oral. Rehabil., 2004, 31, 884–889.

[20] FROMENTIN O., LASSAUZAY C., ABI NADER S., FEINE J., de ALBUQUERQUE Jr R.F., *Testing the retention of attachments for implant overdentures – validation of an original force measurement system*, Journal of Oral Rehabilitation, 2010, 37, 54–62.

[21] SETZ I., LEE S.H., ENGEL E., *Retention of prefabricated attachments for implant stabilized overdentures in the edentulous mandible: an in vitro study*, J. Prosthet. Dent., 1998, 80, 323–329.

[22] SVETLIZE C.A., BODEREAU Jr E.F., *Comparative study of retentive anchor systems for overdentures*, Quintessence Int., 2004, 35, 443–448.

[23] COHEN B.I., PAGNILLO M., CONDOS S., DEUTSCH A.S., *Comparative study of two precision overdenture attachment designs*, J. Prosthet. Dent., 1996 Aug, 76(2), 145–152.

[24] RUTKUNAS V., MIZUTANI H., TAKAHASHI H., *Influence of attachment wear on retention of mandibular overdenture*, J. Oral. Rehabil., 2007 Jan, 34(1), 41–51.

[25] CHUNG K.H., CHUNG C.Y., CAGNA D.R., CRONIN R.J. Jr, *Retention characteristics of attachment systems for implant overdentures*, J. Prosthodont., 2004 Dec, 13(4), 221–226.

[26] PERSSON B.N.J., *Sliding friction*, Surface Science Reports, 1999, 33, 83–119.

[27] PERSSON B.N.J., *On the theory of rubber friction*, Surface Science, 1998, 401, 445–454.