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The analysis of the effect of wrought wire clasps on the conditions of abutment teeth

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Laboratory evaluation of spring constants (*k*) of wrought wire clasps (WWC) separated from removable partial denture (RPD) and the results of tibological tests which represent the dependence of enamel wear with normal force have been presented in the paper. The results of laboratory examinations have been combined with the results of clinical assessment of the level of abutment teeth wear. On the basis of the examinations performed it has been revealed that the following factors have the greatest impact on tribological wear of abutment teeth: the time of using RPD and the normal force exerted by WWC on abutment tooth. Normal force depends to a great extent on the place of contact of WWC with the tooth. It has also been found that abutment teeth featuring higher scale of wear are more loosened. The diameter of wire used for making WWC, total length of the arm and *k* determined for the total length of the arm did not have any impact upon the scale of wear of abutment teeth.

Key words: *wrought wire clasp (WWC), wear, removable partial denture (RPD), spring constant*

1. Introduction

Problems connected with the functioning of the abutment tooth–clasp system concern both the natural condition of the teeth surface and the influence of repeatable displacement of the arm of a clasp under a given load on the condition of teeth. There are no elaborated data regarding that problem in the literature. However the contents of many articles presenting the problem of tribology of human teeth [1]–[4] are strongly related to that area. Recent advancements in identifying mechanical properties [5]–[7] and tribological properties [8]–[10] of the tooth tissue have been possible because, among other things, appropriate examination techniques were introduced [11]–[13]. At the same time, there seem to be no relation between research results and performance of wire clasps (WWC). On the prosthetic market which is greatly determined by the limited financial means of the people, the wire clasps are a popular form of partial prosthetic restoration. The surveys indicate that even up to 70% dentists prefer to use wire clasps [14]. It is commonly believed that the problem of designing functionally unstable dentures does not require further investigation because it has been thoroughly examined and discussed, which is contrary to the opinions of a considerable number of patients who are dissatisfied with their dentures. Therefore it is quite appropriate to conduct research on the ways of eliminating imperfections of these designs.

Clinical success is possible only if the stiffness of WWC is properly combined with the condition of abutment teeth [15]–[16], which, in turn, preserves the remaining dentition of the patients in a relatively good state. It should be stressed that the stiffness of the arm depends largely on the place where the arm contacts a tooth [15]. Shifting the contact point towards the

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place of fixing causes a growth of stiffness and also an increase of load exerted on the tooth at the same time. This results in an increase of friction force and tribological wear [15]. This problem, generally, has not been investigated and presented in the literature yet. There have been no presentations or elaborations concerning wear of lateral surface of teeth by WCs used in RPDs. A significant influence of chemical effect of food components and saliva secretion on the wear of teeth has not been taken into account in related investigations and an attempt has been made to select from the complexity of problems only the phenomena related to clasp–abutment tooth system.

Therefore, the aim of the present research was to evaluate the stiffness of WWC's solutions used in practice and to identify mechanisms which are crucial for the intensity of abrasive wear of abutment teeth. Identification of these mechanisms was based on laboratory examinations and localization of the wear zone in the course of clinical tests.

2. Materials and methods

The examinations of mechanical features were carried out for clasps which were no longer in use in removable partial dentures (RPD). WWC samples which were responsible for abutment teeth wear were selected for the tests. WWCs were mounted again in steel sleeves using epoxide resin. The samples prepared for the tests are presented in Fig. 1. An attempt has been made to select WWCs featuring the greatest similarity of geometrical characteristics in order to facilitate interpretation of the results. Five samples (clasps) made of wire of the following diameters: 0.7 mm, 0.8 mm, and 0.9 mm were prepared (15 samples in total). First, the arm length (l) was measured and next the spring constants (k) of the arms were determined. While measuring k, the samples were loaded by a force of 2.2 N using a spherical penetrator for pressing and the value of displacement was registered at the same time. The force was applied in the plane which represented the arm's bending out resulting from the depth of the tooth undercut at four points successively along the length of the arm (Fig. 1b). These points are denoted as 1, 2, 3 and 4, relative to the percentage of the arm's length use: starting from the free end (100%, point 1 which represented the use of the total length) and moving every 25% towards the shaft up to point 4 (25%). Therefore, k_1, k_2, k_3, k_4 are used as notations for spring constants in this paper. The aim of the analysis of laboratory test results was to find connections between geometrical features of the samples and their stiffness. The results obtained allowed diagrams to be made which showed the range of changeability of k of the clasps examined depending on the active length of the clasp arm. The lines of trend for the mean values of k have been determined. At the same time, finding the mean values of k helped to interpret the results and to carry out further research, i.e., to combine laboratory examinations with clinical tests. Taking into account the fact that the samples tested were the clasps separated from dentures, i.e., the real objects, it was necessary to consider the geometrical differences of particular clasps. This was done by unifying the dependences obtained. These diagrams help to estimate k of the denture clasps in use. The values of k for four points were read from the diagrams in next stages of the analysis and they were: 100%, 75%, 50% and 25% of "active" part of the scale representing the respective length of a clasp arm. Mean values of multiplication factors of k changing for particular "points" of the arm of a clasp have been calculated by dividing the initial value (mean value of k for 100% of the arm of the clasp) by the value read from the diagram for a particular point (e.g., 50% of the active part of the clasp). In the next step, diagrams were made which illustrated the dependences of the mean value of multiplication factors of k change on the active length of the clasp arm expressed in percentage. The purpose of making these diagrams was to enable observation of an impact of the changes of stiffness of the clasps upon the level of abutment teeth wear which was defined on the basis of clinical tests.

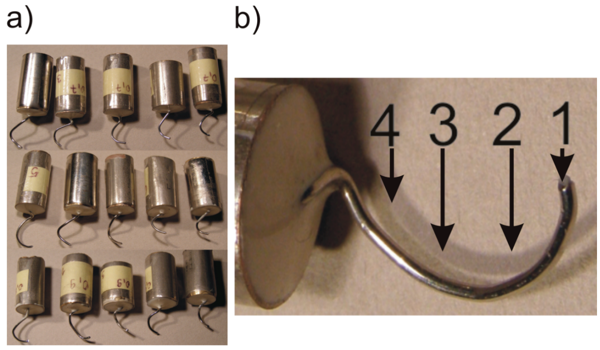

Fig. 1. Samples made of wrought wire clasps for testing spring constants (a) and presentation of applying a load to the samples at four points of the arm of a clasp (b)

Averaged results from the examinations presented above were one of the basis for selecting the parameters of tribological examinations. These examinations were carried out on a test stand of the authors' own construction shown in Fig. 2. The samples

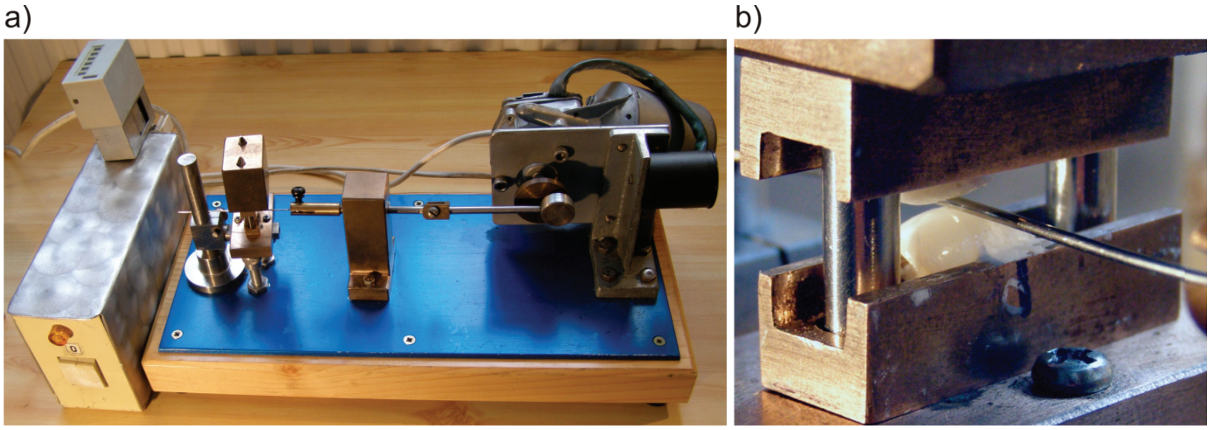

Fig. 2. Test stand for tribological examinations (a) of the samples made of postextraction teeth with a wire sample (b)

simulating clasps were made of stomatological wire of 0.7 mm, 0.8 mm and 0.9 mm in diameter. They were "Z"-shaped in the central part. The samples of the clasps moving forward and backward were pushed between the bottom and the top samples which were cut off from post extraction teeth. The required normal force F_N was applied by putting suitably selected replaceable weights on guiding columns. The following set of normal forces were chosen: 3.5 N, 7 N, 15 N and 30 N. The level of wear of the samples was assessed after 5000 cycles. The difference in the height of the samples (initial height – final height) in the place of contact with a wire sample was regarded as a level of tribological wear of the tooth tissues. The height of the samples was measured by a micrometer with accuracy up to 0.001 mm.

A population of 31 women and 28 men aged 41 to 89 years were qualified for clinical examinations. These were the cases of patients with noticeable wear of the lateral surface of abutment teeth caused by a functionally unstable denture. Medical history of every patient provided information about the period of time each of them used the RPD. Information about diversified period of time of using the denture helped to choose the cases with the wear of tooth enamel caused by the arm of a clasp as a result of excessive load and long-term, repeatable micro-movements in the zone of the neck of a tooth. The period of time when the denture was in use in a group tested ranged from 1 to 12 years.

The diameters of wire used for making the arm of a clasp were measured by a slide caliper. The measurements were carried out for 133 clasps of which 7 were made of wire of 0.7 mm in diameter, 101 of wire of 0.8 mm in diameter and 25 of wire of 0.9 mm in diameter. Next, the length l of each arm of a clasp was measured. Having assessed the parameters which characterized the arm of a clasp, the intraoral examination was carried out which allowed the condition of the clasp surface of the abutment teeth to be evaluated. The following teeth were evaluated: molar teeth (n = 26), premolar teeth (n = 51), and canine teeth (n = 52). The evaluation of the level of wear of abutment teeth was made on the basis of a wear scale of a tooth prepared by the authors. The height of wear was assessed along the path of inserting the denture and the wear was qualified either to group I or II (Fig. 3), at the same time dimensionless value which was 1 for group I and 2 for group II was attached to it, respectively. In the first group, there were cases of clearly noticeable tooth surface wear below the prosthetic equator, mainly in the near-neck zone of a tooth. In the second group, there were cases of noticeable tooth surface wear along the entire surface of a tooth which was in contact with the arm clasp at the time of inserting and taking out the denture. The width of the wear was defined taking into account the length of the arm of the clasp. The clasps were divided into four equal parts in accordance with the principles of laboratory examinations and described by percentage of the length of the arm of a clasp (Fig. 3). The number of zones worn by particular parts of the arm of a clasp was defined. A dimensionless scale of wear was introduced in order to map the total size of wear so that it would make the interpretation of the results easy. The range of changes from 1 to 8 units has been ac-

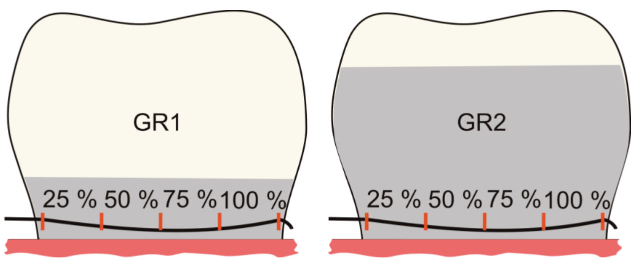

Fig. 3. Presentation of the principles of qualifying teeth wear assumed in the research work

cepted. The result was obtained by multiplying the number of zones of wear (25% – 1; 25% and 50% – 2; etc.) by the value assigned to particular group (1 or 2).

A zone of the highest tribological wear of a tooth surface was also denoted. The zone was defined in the range of 25% to 100% where the deformation of the surface caused by the wear had considerably deformed anatomic structure of a tooth. It ought to be emphasized that this kind of evaluation was the most difficult element of clinical examinations because of individual changes of dentition features. Keeping in mind the fact that there are some imperfections of the method because it is not possible to get accurate measurement data regarding the initial condition of a tooth, these results provide some essential information. Localization of high wear zones is the basis for defining the multiplication factor of stiffness changes of the arm of a clasp in the place of the highest wear (it allows changes of the load of the clasp on a tooth in that area to be estimated). The results concerning basic parameters of the clasps (wire diameter and length "*l*" of the arm of a clasp) were compared to the results of analysis which were obtained in laboratory examinations. Therefore, it was possible to determine *k* of wire clasps (having the lengths of the clasps measured they were read from the diagrams presented in Fig. 3) and the multiplication factor of an increase of *k* of the clasps at the point corresponding to the highest abutment teeth wear (diagrams presented in Fig. 3(b) were used).

Defining the movability of a tooth by Periotest was a supplementary examination for assessing the condition of abutment tooth. The measurement was carried out three times and the mean result was included in the table presenting the results.

Statistical analysis was used for analyzing the results obtained. The following factors were examined: correlation between the wear scale of abutment teeth and the period of time of using the dentures declared by the patients, *k* of wire clasps, multiplication factor of an increase of *k* in the place of maximal wear, wire diameter used for making the clasps and movability of teeth. The assumed statistical significance was at $p(\alpha) < 0.05$. The distribution of variables was not normal so the degree of dependences between the variables was calculated using nonparametric Spearman's rank correlation tests.

3. Results

The lengths of the clasp arms used in the examinations and the obtained values of spring constants *k* are listed in Table 1. The values of *k* increased with the shift of measurement point towards the shank of a clasp arm. However, in the case of measurement point no. 2, corresponding to 75% of the sample length, the registered increase was still relatively small. Furthermore, the samples made of wire of larger diameter featured distinctively higher tendency to increase *k* together with the decrease of total length of the arm clasp.

Table 1. Values of spring constant (*k*) for clasps of different length (*l*) made of wire of three dimensions (Φ) measured at four points of the arm of the clasps

Φ [mm]	No.	*l* [mm]	k_1 [N/mm]	k_2 [N/mm]	k_3 [N/mm]	k_4 [N/mm]
0.7	1	10.8	3.6	4.9	20.8	41.3
	2	10.4	4.6	5.8	24.3	43.1
	3	10.1	5.1	7.3	27.1	48.5
	4	9.7	4.6	6.8	26.9	48.7
	5	9.5	5.5	7.9	28.9	53.7
0.8	6	12.7	3.9	4.8	17.5	42.5
	7	11.1	5.1	6.2	23.8	49.8
	8	10.2	7.8	8.8	26	53.8
	9	9.9	6.7	8.8	27.8	58.5
	10	9.2	11.2	16	38.8	71.7
0.9	11	12.3	8.1	10.2	31.9	51.3
	12	11.6	8.8	11.9	39.3	54.2
	13	10.9	9.4	12.7	42.9	62.7
	14	10.6	9.7	14.2	46.7	73.2
	15	9.1	18.3	27.6	71.2	101.4

Diagrams showing the range of changeability of *k* of the clasps examined depending on the active length of the clasp arm are presented in Fig. 4a. Bold lines are the trend lines for mean values of *k*, whereas thin lines represent a scatter of the registered values in the population tested. Dependences of the mean value of multiplication factor of *k* change on active length of the clasp arm expressed in percentage are presented in Fig. 4b.

Tribological test results are listed in Table 2. Tribological wear of enamel after 5000 cycles at small load (up to 7 N) was inconsiderable. The registered size of wear of the samples increased considerably with the growth of generated load forces which could be seen as a steep segment of the characteristics presented. Smaller wear of the samples registered in the case of using countersample made of wire of larger diameter can be explained by the fact that there is an increase of the real zone of contact of tribological elements system. As a result, the load generated on a unit of surface was slightly smaller while using wire of 0.9 mm in diameter than using wire of 0.8 mm or

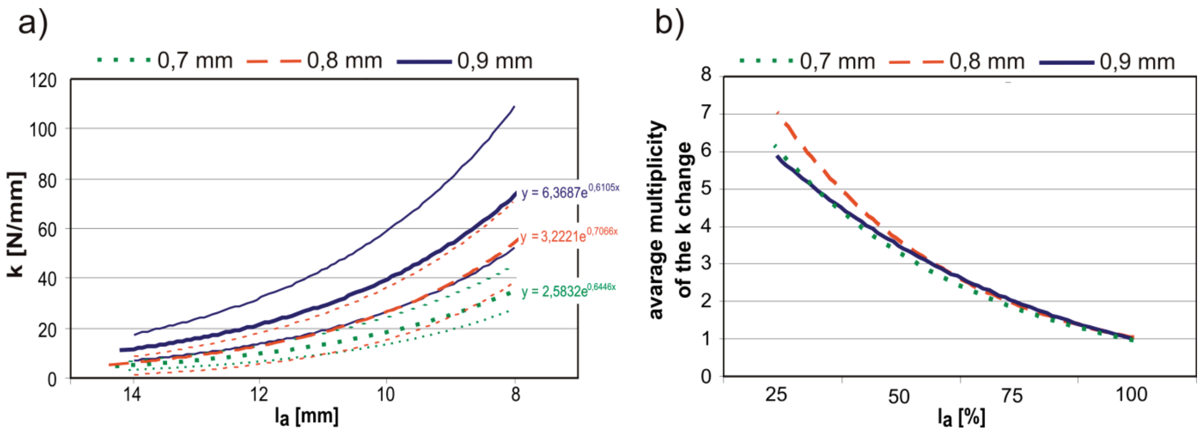

Fig. 4. The impact of active length of the arm (l_a) upon the changes of spring constant k (a) and the mean value of multiplication factor of the change k as a function of active length of the arm in percentages (b) for the clasps made of wire of 0.7 mm, 0.8 mm, 0.9 mm

Table 2. The impact of the value of normal force (F_N) upon the linear wear of enamel after 5000 cycles

Φ [mm]	Linear wear [mm]			
	F_n = 3.5 N	F_n = 7 N	F_n = 15 N	F_n = 30 N
0.7	0.010 ± 0.004	0.027 ± 0.005	0.278 ± 0.043	0.858 ± 0.092
0.8	0.010 ± 0.002	0.025 ± 0.003	0.258 ± 0.039	0.820 ± 0.073
0.9	0.008 ± 0.002	0.020 ± 0.003	0.213 ± 0.036	0.653 ± 0.079

Table 3. Spearman's rank correlations between dimensionless scale of wear and the period of time of using the dentures, spring constant (k) of the wire clasp arms, multiplication factor of the increase k, wire dimension, length of the clasps and the result of teeth movability tests by Periotest

Molar teeth n = 26	R Spearman	$t(n-2)$	p value
Scale of wear [units] vs. time of using the RPD [years]	**0.6461**	4.1470	**0.0004**
Scale of wear [units] vs. wire diameter [mm]	0.0548	0.2688	0.7904
Scale of wear [units] vs. length of the clasp [mm]	0.3712	1.9582	0.0619
Scale of wear [units] vs. k_1 [N/mm]	–0.3400	–1.7710	0.0893
Scale of wear [units] vs. multiplication factor of increase of k [units]	**–0.8449**	–7.7368	**0.0000**
Scale of wear [units] vs. Periotest value [units]	**0.4221**	2.2808	**0.0317**
Premolar teeth n = 51			
Scale of wear [units] vs. time of using the RPD [years]	**0.4705**	3.7329	**0.0005**
Scale of wear [units] vs. wire diameter [mm]	–0.1401	–0.9904	0.3269
Scale of wear [units] vs. length of the clasp [mm]	0.0164	0.115	0.9089
Scale of wear [units] vs. k [N/mm]	–0.0387	–0.2711	0.7875
Scale of wear [units] vs. multiplication factor of increase of k [units]	**–0.8020**	–9.3984	**0.0000**
Scale of wear [units] vs. Periotest value [units]	0.1490	1.0549	0.2966
Canine teeth n = 52			
Scale of wear [units] vs. time of using the RPD [years]	**0.4442**	3.506	**0.0010**
Scale of wear [units] vs. wire diameter [mm]	–0.0657	–0.4653	0.6437
Scale of wear [units] vs. length of the clasp [mm]	–0.0262	–0.1852	0.8538
Scale of wear [units] vs. k [N/mm]	0.0188	0.1332	0.8945
Scale of wear [units] vs. multiplication factor of increase k [units]	**–0.8955**	–14.2284	**0.0000**
Scale of wear [units] vs. Periotest value [units]	**0.3514**	2.6537	**0.0106**

0.7 mm in diameter. This phenomenon was particularly clear to observe when the highest value of load was applied. The results of correlation examinations between a dimensionless wear scale and the period of time of using the dentures, k of wire clasps measured at point 1, multiplication factor of an increase of dimension of wire clasps, length of the clasps and measurement results of movability of teeth by Periotest are presented in Table 3.

The examination results revealed that the longer the time of using prosthetic restoration, the higher the scale of abutment teeth wear was. At the same time, canine teeth and molar teeth of higher movability featured higher scale of wear. The impact of the multiplication factor growth of k of the clasps in p1 plane upon the scale of abutment teeth wear indicates that scale of wear decreases with the growth in the number of multiplication factors. There has been no evidence of the impact of the length of a clasp arm, constant k of a clasp arm defined at point 1 and the diameter of wire used for making a clasp arm upon the scale of abutment teeth wear.

4. Discussion

On the basis of the laboratory tests performed it has been found that the factor which influences k value of WWC the most is the point of applying the load. At the same time the stiffness of a clasp arm increases considerably with the shift of a measurement point towards the arm's shaft. As a result, the load generated by the wire clasps on the surface of enamel depends to a large extent on the place where a clasp arm contacts the tooth. On the basis of tribological examinations it has been revealed that the increase of load causes a significant increase of tribological wear of enamel. Therefore, the stiffness of clasps in the place of contact with abutment tooth is the most important factor which conditions the quantitative wear of abutment teeth, since stiffness determines to a large extent the force applied to a tooth. On the basis of clinical examinations it has been found that the period of time of using the clasps has the greatest impact on the scale of wear which describes quantitatively the abutment teeth wear. At the same time, canine teeth and molar teeth of higher movability featured higher scale of wear. As has been revealed on the basis of statistical examinations, the impact of multiplication factor of growth of k value of a clasp upon the scale of teeth wear implied that there was a decrease of the wear scale when the number of multiplication factors went up, which was rather surprising. This phenomenon has become quite clear after detailed analysis of the input data. It was found to be connected with localization of the place of maximal wear, the contact zone of clasps with abutment tooth and the method of calculating the wear scale. One should keep it in mind that the registered points of maximal wear were situated in one of the four zones (horizontally), closely related to particular parts of clasps. It turned out that the zone of maximal wear was at the same time for each of the abutment teeth analyzed the last zone (counting from the shaft of the arm of a clasp) which was worn (further on, the arm of a clasp was free, i.e., it did not contact a tooth in a mode which would cause wear). However, the highest values of multiplication factor of growth of k are near the shaft of the arm of a clasp (25% or 50% of its length) which averages one or two zones of wear in such cases. As a result, while calculating the scale of wear, the values are considerably low because the component which refers to the wear horizontally is small (1 or possibly 2). This phenomenon is a disadvantage of the method presented. More detailed and more representative results ought to take into account an additional component – the depth of wear. Carrying out approximate measurements of the depth of wear is relatively difficult in clinical practice because it requires not only the selection of appropriate equipment but also applying it inside the oral cavity (not enough space, considerably big curvatures of the surface). Therefore, the only effective solution was to apply a method which would facilitate a qualitative description of tribological wear of teeth without the possibility of its detailed quantitative assessment, including the depth of wear as well.

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