

The role of friction in the mechanism of retaining the partial removable dentures with double crown system

TOMASZ DĄBROWA¹, ANNA DOBROWOLSKA², WOJCIECH WIELEBA^{2*}

¹ Silesian Piasts University of Medicine in Wrocław, Wrocław, Poland.

² Wrocław University of Technology, Faculty of Mechanical Engineering, Wrocław, Poland.

Cylindrical telescopic crowns belong to bolt dentures, because their adhesion strength is based on the friction force. The magnitude of static and slide friction forces depends on the strain within the contact area and properties of materials employed. Friction force value between telescope elements declines in the first phase of wearing period and, subsequently, maintains particular constant value of 8 to 10 N. In the telescopic technique, homo and heterogenic joints are used. The following prosthodontic materials have been examined: gold-base alloys (Degudent Kiss, Degulor M), cobalt-base alloy (Brealloy 270), ceramics (Zircon Oxide, Zirconia) during tribological investigations on FGP composite resin. The cooperating surfaces were moistened with synthetic saliva. The research confirmed the dependence of the static friction coefficient on the contact pressure for the analyzed pairs of materials used in prosthodontics. The biggest effect of the contact pressure on the coefficient of friction value occurs when the ceramic rubs on FGP composite resin. The most stable friction coefficient in the context of contact pressure changes as well as life has been found in the case of the cobalt alloy Brealloy 270. An interesting material is a gold alloy Degulor M, for which the coefficient of friction varies only slightly with pressure in the range of 0.6 to 0.9 MPa.

Key words: dental crown, friction, prosthodontic materials

1. Introduction

A double crown system enables fastening of the partial removable dentures on single pillars, which have remained in residual or reduced dentition. It is acknowledged that such crown construction allows occlusive forces to be directed along the axis of abutment teeth, which provides favorable conditions for their longer retaining in the alveolar ridge. A telescopic crown consists of two crowns, that is, an internal crown or a primary part and an external crown, or a secondary removable part [1]–[9]. Examples of fastening telescopic crowns are presented in Fig. 1. The forces that keep partial removable dentures in the prosthetic base are released due to the complex tribological mechanisms.

Cylindrical telescopic crowns belong to bolt dentures, because their adhesion strength is based on the friction force, which arises during the movement of the two parallel surfaces of the crowns. The friction force, arising when the secondary part is moving against the primary part of the latch, is called the slide friction. Friction effects, which come to existence within the contact of metal surfaces, generate so-called joint area. The magnitude of static and slide friction forces depends on the strain within the contact area and properties of materials employed. When the surfaces of telescopes cooperate, the polished surface of internal crown comes in contact with internal surface of metal-ceramic external crown. The actual contact area is a sum of contact surfaces within micro irregularities of materials, which undergo plastic strain, according to the pressure occurring in the contact

* Corresponding author: Wojciech Wieleba, Wrocław University of Technology, Faculty of Mechanical Engineering, B5, room 207, ul. Łukasiewicza 7/9, 50-371 Wrocław, Poland. Tel: (071) 320 27 74, e-mail: wojciech.wieleba@pwr.wroc.pl

Received: May 21st, 2013

Accepted for publication: June 26th, 2013

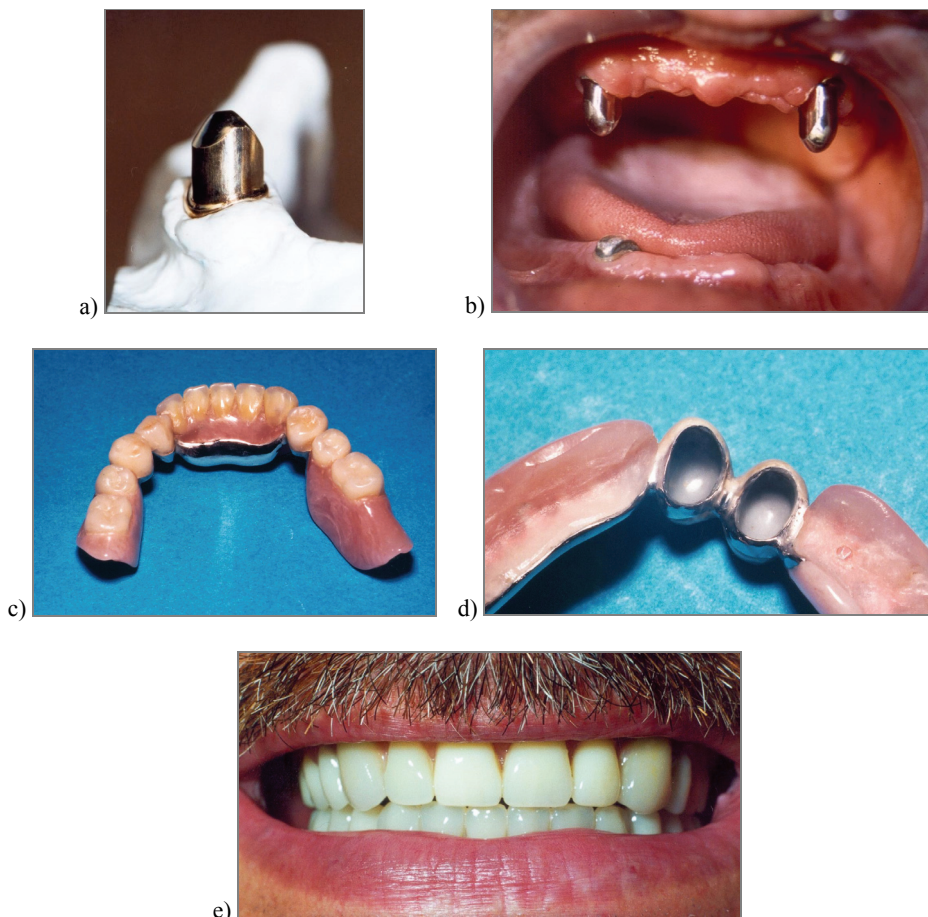


Fig. 1. Examples of fastening telescope crowns: (a), (b) internal crowns (primary parts), (c), (d) external crowns (secondary removable parts), (e) the double crown system in the mouth

area. As the friction surfaces approach the molecular level, strong adhesive interactions arise. Friction force value between telescope elements declines in the first phase of wearing period and, subsequently, maintains particular constant value of 8 to 10 N [10]–[14].

The presence of saliva makes the friction in telescope junctions usually take place in mixed friction conditions [2]. Total friction force F_t results from the sum of resistance of dry friction F_D , boundary lubrication F_B and lubricated friction F_L (Fig. 2) [15], [16].

$$F_t = F_D + F_B + F_L$$

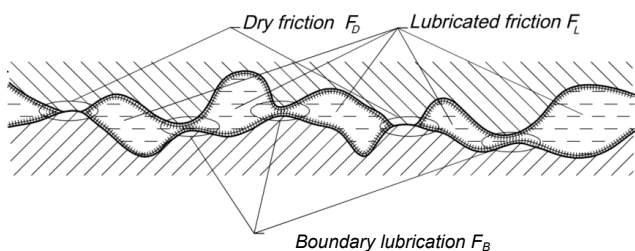


Fig. 2. Scheme of the mixed friction

Obviously, dry friction contributes to much bigger friction resistance than the mixed or boundary friction. The participation of particular friction resistance components is dependent on both features of all materials taking part in the friction process, i.e., materials that form a rubbing set, and a slide liquid (saliva) as well as friction process parameters (e.g., dwell time under load, surface roughness, etc).

The presence of saliva, which enhances the adhesive effect, has an additional positive influence, as it protects both surfaces of the crowns against excessive material loss.

The magnitude of friction force, which contributes to proper functioning of telescopic crowns, is mainly dependent on the contact between mating surface of telescope parts. That pressure, in turn, depends on the difference between internal and external dimensions of telescope parts. Three types of engineering fits: transition (close) fit, interference fit and clearance fit, are distinguished among mechanical joints.

Transition (close) fits are not used in prosthodontics considering the need to apply some considerable

force to connect both elements. In such a case, parts that are fitted get wedged, and the combination becomes hardly separable. That type of fit occurs when the primary part is of a bigger diameter than the secondary part of telescopic latch.

Interference fit applied in the cylindrical double crown technique. The size of diameter of both elements is being determined during their retaining, so that inserting the secondary part on the primary part is possible. That type of fit demands huge precision in laboratory proceeding. Thanks to the roughness of denture wall surfaces the friction force arises that contributes to retaining the denture in its basis. In the first phase of such exploitation of dentures the interference fit is present, and the retention force factor varies from 8 to 10 N. Mechanical and adhesive interactions, produced by the secondary and primary parts of telescope latch moving towards each other, result in a gradual surface attrition and down force reduction, followed by retaining force reduction. Such a situation happens after a longer, several years' period of wearing the dentures. The interference fit life span depends, among other things, on the size of contact surface between the primary and secondary parts of the latch. But in spite of applying precise apparatus, fulfilling that condition seems very hard.

The clearance fit arises after a long time wearing period. As a result, cylindrical crown surfaces are tired. Parts of cylindrical telescope may be dowelled practically without a clamp, which is necessary for the adequate friction effect to occur. What characterizes that type of retention is a significant decrease in friction force rate to about 2 N. The necessity to activate latches or to apply additional retention units then appears.

2. Materials and methods

In the telescopic technique, homo and heterogenic joints are used. Both parts of homogenous friction set are made of the same material, while in heterogenic combinations the materials used are different. Heterogenic sets are much more commonly employed. To make primary elements, harder alloys like, e.g., cobalt-chrome-molybdenum alloys or strong gold alloys are then used. Zircon oxide is increasingly employed in this group. Secondary elements are made of softer alloys, which are able to retain to primary elements, like gold alloys or special composites. FGP two-component polymer composite belongs to that group. This composite has a fluid consistency, and becomes hard only after the polymerization process has been

completed, which guarantees precise coating and that the surface formed will adhere fully to the element in contact.

In the framework of tribological research, the following prosthodontic materials with specific surface roughness have been examined:

- gold-base alloy Degudent Kiss (surface roughness $Ra = 0.44 \mu\text{m}$),
- gold-base alloy Degulor M (surface roughness $Ra = 0.51 \mu\text{m}$),
- cobalt-base alloy (Brealloy 270) (surface roughness $Ra = 0.35 \mu\text{m}$),
- ceramics (Zircon Oxide, Zirconia) (surface roughness $Ra = 0.02 \mu\text{m}$).

Specimens of the materials examined were of cuboid tiles shape. During tribological tests the flat surface of specimens cooperated with the counter-face, made from FGP composite resin. Surface roughness of the counter-face was $Ra = 0.5 \mu\text{m}$. All specimens were tested under load in a manner that allowed equal contact pressure to be achieved within 0.5 to 1.0 MPa. To obtain the most precise conditions, present in the mouth, the cooperating surfaces were moistened with Mucinox – a preparation of synthetic saliva, based on natural mucin.

The research of the static friction of selected material combinations was conducted on a test rig for testing friction in the rolling-sliding motion [9]. The test rig was adapted to the research of static friction within the reciprocating motion, and its diagram is presented in Fig. 3.

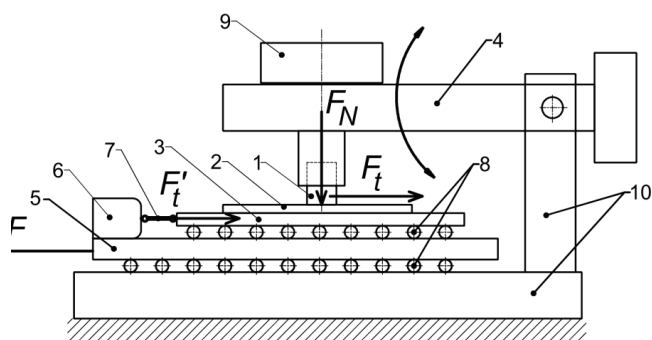


Fig. 3. Scheme of the test rig for testing static friction:
1 – polymer specimen, 2 – metallic counter-face,
3 – table, 4 – lever, 5 – mobile base, 6 – force sensor,
7 – rod, 8 – linear guides, 9 – weight, 10 – housing

General operating principle of the test rig for the research of static friction is based on the increase of the force F , whose task is to shift the mobile base (5). As the resistance opposing this movement, there appear friction forces between the specimen (1) of the test material and metallic counter-face (2), and the rolling

resistance in the linear guides (8). The specimen (1) is mounted in the holder, located at the end of the swing lever (4), with the counter-weight balancing its weight. Above the specimen the appropriate weight (9) is situated, that causes specified value of normal force F_N , charging the rubbing pair tested (specimen-counter-face). The friction force F_t between the specimen (1) and the counter-face (2) is transmitted by the table (3), located on the guide (8) and rod (7), into the force sensor (6). Because the resistance of friction in the guides with the rolling elements is many times smaller than the frictional force F_t , it can be assumed that force F_t' , recorded by force sensor (6), is approximately equal to the force of friction F_t in the rubbing pair tested.

3. Results

The static friction coefficient was examined for two periods of rubbing set exploitation:

Stage I (break-in) – early period of examined combination of materials exploitation – a break-in stage – after several cycles of reciprocating motion at a movement amplitude of 10 mm.

Stage II (final exploitation period) – after performing 10 000 cycles of reciprocating motion at a movement amplitude of 10 mm.

The number 10 000 cycles was assumed regarding that approximately five times a day the denture is put on and taken off. That number refers to a five-year-period of the telescopic denture usage.

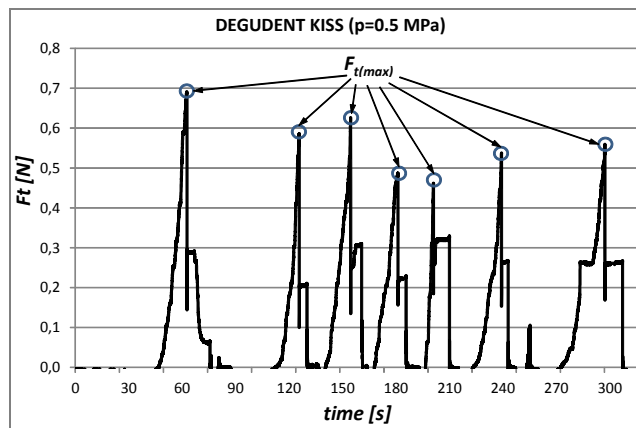


Fig. 4. Example of the frictional force F_t (N) measurement for Degudent Kiss material, cooperating with FGP composite resin

A graph in Fig. 4 shows recorded values of frictional force. During every experiment, the maximal

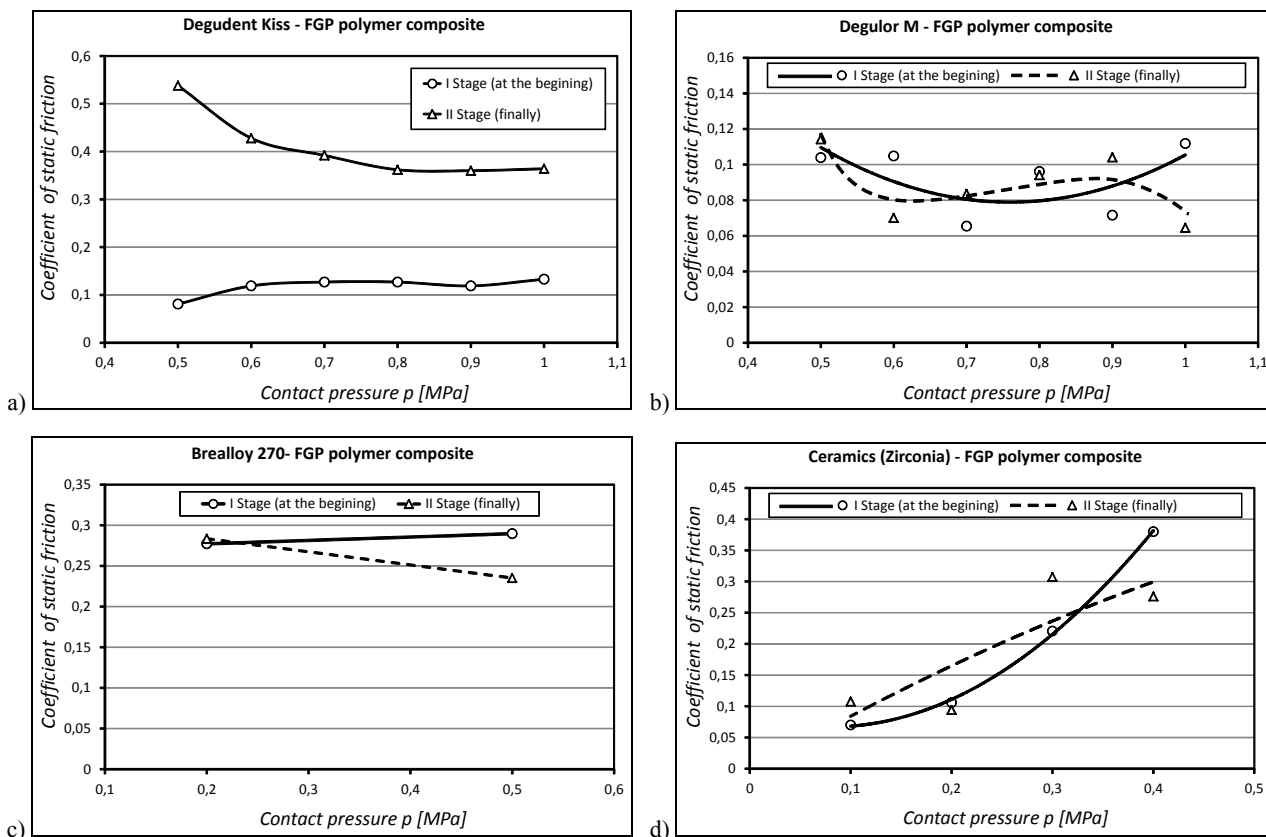


Fig. 5. Dependence of the friction coefficient of the contact pressure (Stage I – lapping, Stage II – after 10 000 cycles of motion) for materials of slide cooperation with FGP polymer composite: (a) Degudent Kiss, (b) Brealloy F270, (c) Degulor M, (d) Ceramics

force $F_{t(max)}$ determined the force of static friction $F_{t(stat)} = F_{t(max)}$, which was then used to define the static friction coefficient

$$\mu_{stat} = \frac{F_{t(stat)}}{F_N}, \quad (1)$$

where

- $F_N = p \cdot A$ – normal force (N),
- p – medium contact pressure (MPa),
- A – contour-contact area of cooperating elements in the rubbing set (mm²).

The results of measurements in the form of friction coefficient depending on the contact pressure are presented in Fig. 5. The graphs provide values of the coefficients of friction in the primary (stage I) and final (stage II) period of use.

The results of friction coefficient examination enabled the frictional force to be determined at a pre-determined pressure p on the unit contact area A . The predicted friction force can be determined using a transformed formula (1) and the results of the coefficient of friction examination, depending on the contact pressure

$$F_{t(stat)} = \mu_{stat} \cdot p \cdot A_{nom}. \quad (2)$$

The average nominal contact area of telescopic elements of the dentures, which is $A_{nom} \approx 110 \text{ mm}^2$, was adopted for the calculation. Graphs presenting the frictional force dependence of the contact pressure for such a contact surface are shown in Fig. 6. The area where friction force is in the range 8–10 N is marked in the graphs. In such conditions the optimum interference fit is provided – the one that allows for a smooth removal of the dentures while ensuring that it does not move during everyday use.

4. Discussion

The present research confirmed the dependence of the static friction coefficient on the contact pressure [16] for the analyzed pairs of materials used in prosthodontics. Contact pressure in the elements of telescopic dentures is obtained by an adequate interference, resulting from the fitting of linear dimensions of the cooperating elements [8]. At the given contact surface, static frictional force depends on both the contact pressure and the coefficient of the friction value. That force guarantees maintaining dentures on

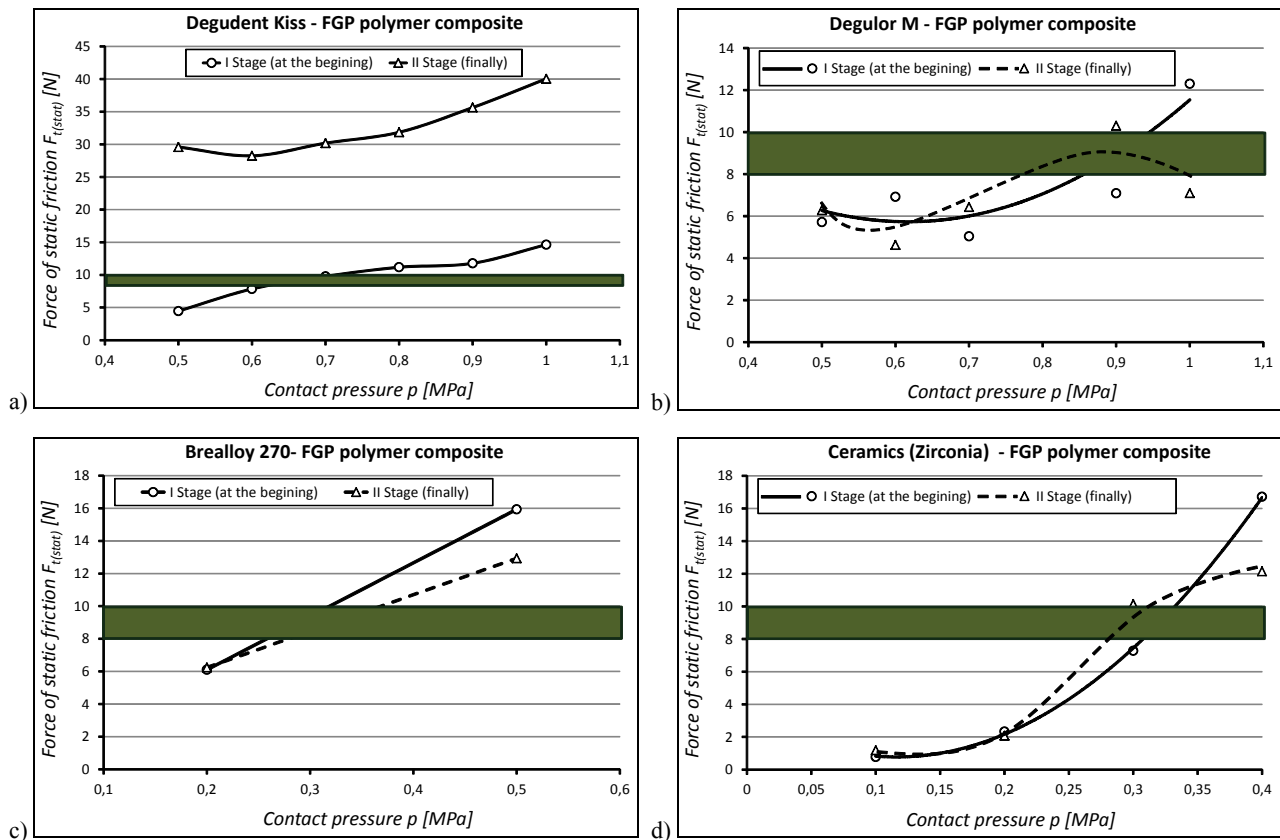


Fig. 6. Graph showing the variation of the total force of static friction (Stage I – lapping, Stage II – after 10 000 motion cycles) for materials of slide cooperation with FGP polymer composite: (a) Degudent Kiss, (b) Degulor M, (c) Brealloy F270, (d) Ceramics

the telescopic elements. Along with wearing out materials of the telescopic elements during the use of dentures, retention of dimensions of those elements will be subject to change, and the contact pressure will decrease. Together with the contact pressure, the frictional force will decrease.

Based on the results of the research conducted, the following conclusions can be formulated, regarding the selection of materials for the telescopic elements, and the recommendations concerning selection of the contact pressure in the parts of telescopic dentures:

The lowest values of the coefficient of static friction ($\mu_{\text{stat}} = 0.06\text{--}0.165$) were observed for the gold alloy Degulor M, while the largest values ($\mu_{\text{stat}} = 0.35\text{--}0.55$) for the gold alloy Degudent Kiss, in the final stage of exploitation (after 10 000 cycles of motion).

The biggest effect of the contact pressure on the coefficient of friction value occurs when the ceramic rubs on FGP composite resin (Fig. 4d). For such cooperation, even a slight change of pressure can result in significant reduction of static friction force and, consequently, can reduce the effectiveness of retaining the dentures. This means that to generate the proper contact pressure, in the case of ceramics high precision of telescopic elements will be required. The study shows that it should be 0.3–0.35 MPa for materials in the telescopic elements, amounting to contact surface $A_{\text{nom}} = 110 \text{ mm}^2$. The static friction force will be then 7–11 N.

The most stable friction coefficient in the context of contact pressure changes as well as life shows the cobalt alloy Brealloy 270. In the case of this material the optimum contact pressure range is 0.25–0.35 MPa. In this pressure range, the static friction force is 8–10 N assuming that the contact surface is $A_{\text{nom}} = 110 \text{ mm}^2$.

An interesting material is a gold alloy Degulor M, for which the coefficient of friction varies only slightly with pressure in the range of 0.6 to 0.9 MPa. Therefore, with a suitably selected contact surface, assumed force of friction can be obtained, which will vary slightly with the change of pressure (Fig. 6b). This ensures proper retention of dentures with telescopic elements despite the reduction of pressure, resulting from the wear of materials. That surface should be slightly bigger by 110 mm^2 to get greater value of friction force at a lower contact pressure.

The problem of friction in the elements of telescopic dentures is complex and requires further studies and research. Especially important may be the shape and surface roughness of contacting components [2], [17]. These issues should be continued in the next stages of the research.

References

- [1] BESCHNIDT S.M., CHITMONGKOLSUK S., PRULL R., *Telescopic crown-retained removable partial dentures: review and case report*, *Compend. Contin. Educ. Dent.*, 2001, Vol. 22, 927–934.
- [2] BEUER F., EDELHOFF D., GERNET W., NAUMANN M., *Parameters affecting retentive force of electroformed double-crown systems*, *Clin. Oral Invest.*, 2010, Vol. 14, 129–135.
- [3] DĄBROWA T., PLAWSKI A., *Possibilities of prosthodontics treatment with removable partial dentures and telescopic double crowns system*, *Dent. Med. Probl.*, 2011, Vol. 48(1), 97–102.
- [4] EITNER S., SCHLEGEL A., EMSKA N., HOLST S., WILL J., HAMEL J., *Comparing bar and double-crown attachments in implant-retained prosthetic reconstruction; a follow-up investigation*, *Clin. Oral Implants. Res.*, 2008, Vol. 19, 530–537.
- [5] GERNET W., ADAM P., REITHER W., *Nachuntersuchungen von Teilprothesen mit Konuskronen nach K.H. Körber*, *Dtsch. Zahnärztl. Z.*, 1983, Vol. 38, 998–1001.
- [6] GROSSMAN A.CH., HASSEL J., SHILLING O., LEHMAN F., KOOB A., RAMMELSBERG P., *Treatment with double crown-retained removable partial dentures and oral health-related quality of life in middle and high-aged patients*, *Int. J. Prosthodont.*, 2007, Vol. 20, 576–578.
- [7] MANES F.J.F., MARTINEM G.A., OTEIZA G.B., BOUAZZA J.K., BENET I.F., CANDEL T., *A telescopic crowns in adult case with lip and palate cleft. Update on the etiology and management*, *Med. Oral Patol. Oral Cir. Bucal.*, 2006, Vol. 11, 358–362.
- [8] SASSEN H., *Functional parameters and occlusion of partial dentures as a function of the type of attachment*, *Dtsch. Zahnärztl. Z.*, 1990, Vol. 10, 576–578.
- [9] YAMAUCHI E., *Case report of cone crown telescopic denture for bilateral lower free and missing*, *Nihon Hotetsu Shika Gakkai Zasshi*, 2008, Vol. 52, 556–559.
- [10] COCA I., LOTZMANN U., PÖGGELER R., *Long-term experience with telescopically retained overdentures (double crown technique)*, *Eur. J. Prosthodont. Restor. Dent.*, 2000, Vol. 8, 33–37.
- [11] DĄBROWA T., PANEK H., NAPADLEK P., *8-year clinical observation of telescopic anchors applied in removable dentures – case report*, *Dent. Med. Probl.*, 2007, Vol. 44(4), 521–525.
- [12] WENZ H.J., HERTRAMPF K., LEHMANN K.M., *Clinical longevity of removable partial dentures retained by telescopic crowns: outcome of the double crown with clearance fit*, *Int. J. Prosthodont.*, 2001, Vol. 14, 207–213.
- [13] WIELEBA W., KOWALEWSKI P., *Device for testing friction in rolling-sliding motion*, Patent Application P.382893.
- [14] WÖSTMANN B., BALKENHOL M., WEBER A., FERGER P., REHMANN P., *Long-term analysis of telescopic crown retained removable partial dentures: survival and need for maintenance*, *J. Dent.*, 2007, Vol. 35, 939–945.
- [15] BUSHAN B., *Modern tribology handbook*, CRC Press, Boca Raton, Florida, 2001.
- [16] LAWROWSKI Z., *Tribology. Friction, wear and lubrication*, Wrocław University of Technology Publishing House, Wrocław, 2008.
- [17] MENGEL R., KREUZER G., LEHMAN K.L., FLORES-DE-JACOBY L., *A telescopic crown concept for the restoration of partially edentulous patients with aggressive generalized periodontitis: A 3-year prospective longitudinal study*, *Int. J. Periodontics Restorative Dent.*, 2007, Vol. 27, 231–239.