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Retention force assessment in conical crowns in different material combinations

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The puprose of this study was to evaluate retention force of conical double crowns in two material connections: gold casting alloy/gold casting alloy and gold casting alloy/gold electroforming alloy. 12 crown pairs of both material connections with the cone angles of 2°, 4° and 6° were made. Experiment of 10.000 in-and-out cycles was performed using a new device which allows the retentive force to be measured in continuous way without necessity of moving the samples to another device. It has been found that the higher the retentive force values, the lower the cone angle. Dispersion of the retention value was similar in both groups, but when cone angle was 2° or 4°, stability of retention force with the passage of time was higher in combinations with electroformed copings. The optimum solution was the cast alloy/cast alloy connection but only with cone angle 6°. However, retentive values seem to be too low to achieve proper retention of dentures.

Key words: *retention force, conical crowns, gold casting alloy, gold electroforming alloy*

1. Introduction

Removable dentures supported by double crowns have been successfully used for years in dentistry. The crowns are usually conically shaped, or cylindrical. Conical double crowns are used both in partially dentate patients, including those with compromised dentition, and in edentulous subjects with dental implants [1]–[4]. They offer a safe way to combine teeth and implants in one construction [5]. Proper functioning of this type of dentures is largely dependent on precision both in the dental surgery and laboratory, on the experience of dental technicians and clinicians and on the course of technological processes associated with denture making. Their manufacturing process, especially in the case of traditional lost-wax technique where both the primary and secondary crowns have to be hand-made and fitted, depends on technician's skills and precision and this makes sometimes the final effect difficult to predict.

Ensuring proper retentive force is indispensable for normal functioning of conical crown dentures. This force should be neither too strong so as not to damage the periodontium or implant connection when the denture is taken off, nor too weak, to prevent uncontrolled loss of retention during mastication. However, above all, the retentive force should be characterized by a possibly constant value both with reference to the successive removal/insertions and long-term wear. This can be achieved only when permanent conditions of widely understood tribology effects between contact surfaces of primary and secondary crowns are maintained. This, however, is difficult to obtain in practice. In order to improve retentive force stability, novel constructions and technologies with the use of new material combinations are implemented [4]–[8]. Due to the advancement of prosthetic techniques used

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for the double crowns, electroforming and CAD-CAM methods can be employed, apart from the classic lost-wax casting method. The use of electroforming to produce a secondary crown eliminates the hand-modelling phase and fitting, as the secondary crown is electrolytically made on the primary crown. It has also been shown that the use of leucite ceramics (Empress® 1) for the primary crown and the use of the electroforming method to make the secondary crown may bring promising results, both in terms of retentive force and its repeatability [8].

The implementation of new options for conical crowns, both in terms of construction, technology or material, requires testing, with special attention paid to the value and stability of the retentive force. In earlier long-term follow up studies analyzing operational reliability of dentures made in different technologies it was found that use of electroforming in manufacturing double crown dentures gives rise to much higher percentage of mechanical failures. More complicated constructions in which electroformed copings are glued into metal framework makes the denture more susceptible to mechanical failures like copings coming unstuck, veneering material chipping or framework fractures [9]. That is why a question arises whether use of these new technologies like electroforming is really worth taking the risk of higher failure rates. For obvious reasons, broad-scope studies can only be performed in vitro. Up to now, no standard has been designed for such studies, and many different methods and appliances have been used. One of the simpler techniques is to measure the retentive force by manual separation of denture components using a standard dynamometer [10]. However, such measurements provide only limited data concerning retention and a long-term research is impossible to perform. Currently, a two-stage test procedure is a major technique. During the first stage, the definite number of joining and separating cycles are performed using a specially designed device and then the pair tested is fixed onto another appliance where measurements are performed to measure the retentive force [4], [8], [11], [12]. This procedure shows the empirical relationship between the number of cycles and retentive force. However, a comparison of results reported by various authors reveals a fundamental inconsistency, more in the character than in the value of the changes observed. Some investigators have found a decrease in retentive force along with an increasing number of cycles, whereas others have reported a non-established character of changes, including increase [4], [8], [11], [13]. One of the reasons may be that the first experimental phase is performed either in dry conditions or in the presence of artificial saliva [8], [11]–[14]. Also measurements of retentive force during the second phase of experiments were usually conducted dry, even if a liquid environment was used in the first phase [8], [12]. Moreover, process of sample removal from the testing machine and mounting it on the measuring device can cause differences in position of inner and outer crown relatively to each other. If this is so, it can have influence on reliability of measurements, because together with changing position of one of the crowns, retention force is changing, too. However, more important is that the authors cited above seem to focus rather on tendencies in the changes in retentive force and not on its stability [8], [11]–[13]. Despite the considerable dispersion of the experimental data, Weigl and Lauer [8] were the ones to notice the significance of this problem for the functioning of dentures supported by conical crowns. The repeatability of retentive force is the key problem here, for it is the great variation of the retentive force values between the successive joining/separating cycles, and not the averaged force value that determines proper retention of the connection. This two-phase procedure cannot be employed for the experimental testing of retentive force stability as it does not allow step-by-step recording, being only capable of recording changes in retentive force in the respective cycle intervals. In this way, it precludes the analysis of the “history” that is hidden in an averaged course of changes.

Since the methods used so far to test retention have major limitations, the authors made an attempt to design a device that would allow more complete analysis of changes in retentive force of conical crowns. It was accepted that the retentive force would be measured for each joining/separating cycle, and that both joining of the denture components and their separating as well as the accompanying measurement of retentive force would be performed on the same device. The potential of the device was verified experimentally, assessing the effect of the crown taper and type of the materials combination on the level and stability of retentive force. With the use of the new device an experiment was planned, the objective of which was to:

1. asses retention force values depending on geometrical parameters of conical crowns;
2. asses retention force values depending on technology and material used to make primary and secondary crown in combinations: cast gold/cast gold or cast gold/electroforming;
3. determine retentive force kinetic characteristic depending on technology and material used to make conical double crowns;

4. asses changes in retention force values depending on the number of in-and-out cycles corresponding to insertion and removal of dentures in different technological and material combinations.

2. Materials and methods

The following sets of samples were prepared for testing the retentive force of conical double crowns:

1. Primary crown – gold casting alloy, secondary crown – gold casting alloy (Group 1).
2. Primary crown – gold casting alloy, secondary crown – made of pure gold by electroforming (Group 2).

In both groups, sample sets were produced with the cone angles of 2°, 4° and 6°. For each set, 12 identical combinations were prepared, giving the total number of 72. All primary crowns were mounted on identical abutments made of non-precious Heranium Na alloy (Heraeus Kulzer, Hanau, Germany) and supplied with a cylindrical handle enabling their fastening. The shape of the crown part of the abutment was a copy of randomly chosen average lower canine, prepared with a moderate chamfer margin with average length of 6 mm measured from the margin of the preparation to the apex of abutment. The height of working walls of the abutment was 5 mm.

In group 1, the primary crowns were made of precious alloy Aurix L60 (Safina, Jesenice, Czech Republic) by the casting method. The crowns were modelled using milling blue wax (Renfert, Hilzingen, Germany) to obtain a preliminary shape and were then milled on a Degussa F1 milling machine (GB Dental, Wesseling, Germany) with 2°, 4° and 6° wax milling burs (Dr. Hopf, Langenhagen, Germany). After casting and preliminary processing of the casts, the axial walls were milled with 2°, 4° and 6° metal milling burs (Dr. Hopf). The secondary crowns were modelled on the primary crowns together with handles shaped as those on the abutments. Then, they were cast from the same alloy as the primary crowns, cleaned from investment remains and potential artefacts from the casting process and fitted onto primary crowns.

In group 2, the primary crowns were manufactured as in group 1, whereas the secondary crowns were prepared by electroforming. The primary crowns were coated with approximately 12 μm layer of electroconductive varnish Preciano Silberleitlack TK (Heraeus Kulzer, Germany). Next, they were placed in a galvanizer Combilabor CL-GF (Heraeus Kulzer) and poured with gold sulphate solution Precjano Gold (Heraeus Kulzer). During the electroplating cycle of 9-hour duration, a 0.3 mm thin layer of gold was created, forming a coping of the secondary crown on the primary one. Afterwards, the copings were placed in a liquid dissolving metallic varnishes. The electroplated copings so produced were cemented into handle moulders using Nimetic-cem cement (3M Espe, Seefeld, Germany). Photographs of the two sets of crowns prepared for testing are shown in Figs. 1a and 1b.

Fig. 1a. Sample of primary cast crown
and secondary electroformed coping prepared for testing

Fig. 1b. Sample of primary and secondary cast crowns
prepared for testing

During the experiment 10.000 joining–separating cycles of the testing samples were carried out at a loading force of 75 N. The value of the loading force was chosen based on the work of Ohkawa et al. [13], who revealed that the retentive force in the double crowns increases with a rise in the loading force, but only to 50 N. Above this level, the retentive force does not practically depend on the loading force applied previously. Since during testing the loading force may show slight fluctuations, the accepted value of 75 N is expected to ensure steady test conditions. The duration of a single cycle, i.e., between successive loadings, was 1.8 s. An example of cyclic loading of a testing sample and retention force measurement is presented in Fig. 2. The loading curve shape approximates positive half of a sine curve, i.e., corresponds to mastication pattern [15].

For the purpose of planned experiment a tribometer used for testing the properties of enamel and dental materials was modified [16]. It operates through the pneumatic system for the loading of double crowns samples tested and provides computer control of load–unload cycle parameters. Pneumatic driven beam makes downward and upward movements, which corresponds to denture insertion and removal. All parameters of the load cycle as well as gauges readings were transmitted to the computer where data was collected. Also, owing to special computer programme invented in Faculty of Mechanical Engineering, Białystok Technical University, basic parameters of the cycle, i.e., load amplitude, duration, intervals between successive loading cycles, were defined. Intervals between cycles were set for 1.8 s. The possibility of performing subsequent loading cycles without separating the primary crown and coping is an essential feature of this device and corresponds to denture loading during mastication. Therefore, it was possible to implement such a test protocol in which subsequent joining and separating of the connection were divided with a definite number of load cycles (masticatory events) without separation. This may be particularly important as nominally immobile connections used, e.g., in technical devices, show micro movements when being loaded, promoting the so called fretting, i.e., a destructive process within the area of the contacting surfaces [17].

Test was performed with all the samples submerged in artificial saliva flow prepared according to Fusayama et al.'s instructions [18]. The thermostatic system allowed the temperature to be maintained at a steady level approaching that of the human body. Except for the thermostatic regulation, constant flow of liquid also ensured systematic removal of wear products off the friction area.

For statistical analysis, due to certain data diversity, the Kruskal–Wallis test of significance was used. Differences were considered statistically significant at $p < 0.001$. The course of retention force changes obtained during laboratory test was smoothed out by trend line with the use of running mean with a step of 200. For this purpose Excel software (Microsoft Office, Seattle, USA) was used. For estimation of retention force changeability, special parameter called running standard deviation was elaborated. This parameter by analogy to running mean was calculated as standard deviation from consecutive 200 measurements of the retention force. For graphic comparison of data obtained this way for each group median, maximum, minimum and quartile 25–75% were calculated.

3. Results

As the measurement data stored in the computer contain complete courses of the forces recorded by strain gauges and refer both to the loading and unloading forces (as shown in Fig. 2), at the beginning only retentive force values were selected from each course. To do this, a special procedure was developed in Excel calculation sheet that would allow identification of the minimum for each single cycle corresponding to the retentive force value. The results showing the retentive force kinetics averaged from 12 measurements for each study variant are presented in Figs. 3a, 3b and 3c.

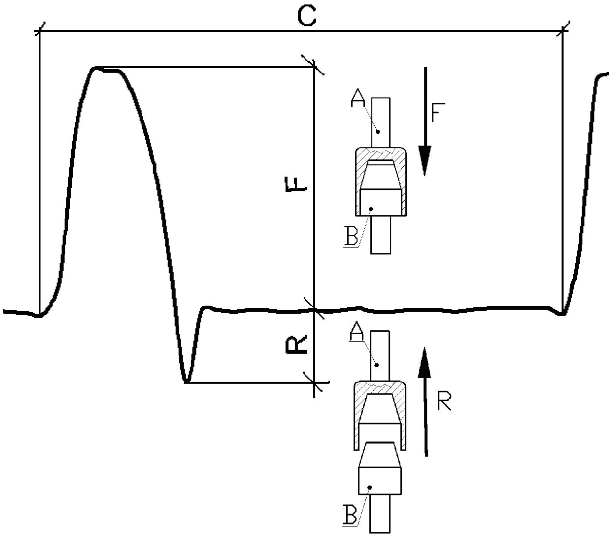

Fig. 2. Sample loading pattern: C – single-cycle time; F – maximum loading force; R – retention force (A – secondary crown, B – primary crown)

The graphs presented in Figs. 3 demonstrate significant differentiation in the level of retentive force depending on the cone angle of crowns which can be observed in the groups tested. The higher the angle value, the lower the average of the retentive force. However, the retention decrease was greater when the secondary crowns were cast from precious alloy (group 1), as compared to those produced by electroforming (group 2). With the cone angle of 2°, the mean value of the retentive force in both experimental groups showed slight fluctuations, except for a certain variation in the kinetics of changes between the groups in the initial phase. The crowns of 4° and 6° taper showed a tendency toward a smaller or greater decrease in the average retentive force throughout the experiment.

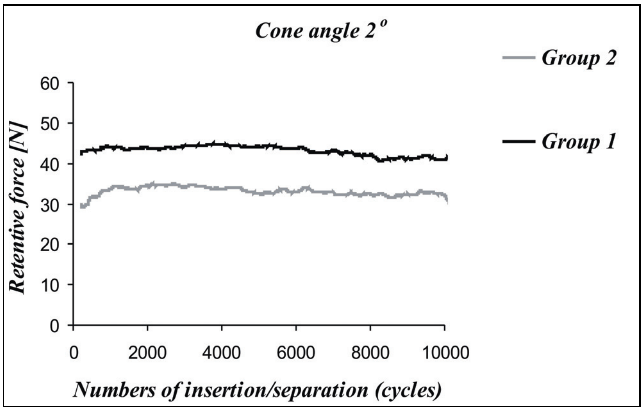

Fig. 3a. Kinetics of the retention force for cone angle 2° (running averages)

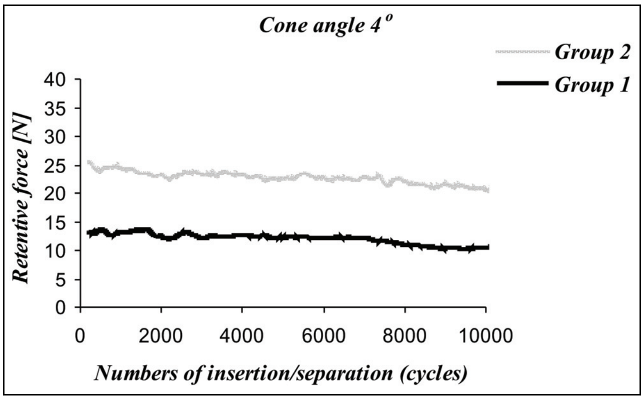

Fig. 3b. Kinetics of the retention force for cone angle 4° (running averages)

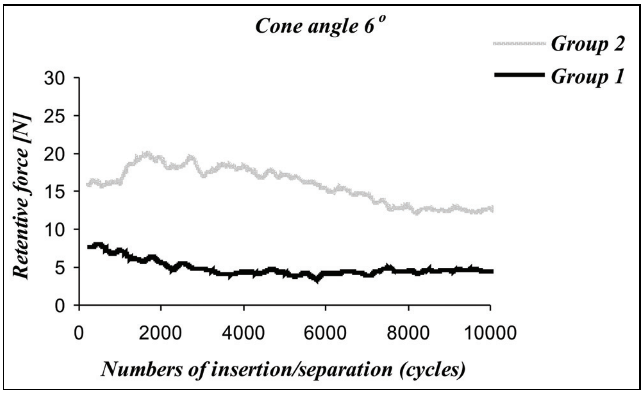

Fig. 3c. Kinetics of the retention force for cone angle 6° (running averages)

The findings obtained for single measurements indicate wide dispersions of retentive force values, which at first glance do not depend on the study variant. Figures 4a and 4b present example courses of changes in the retentive force. However, as opposed to Figs. 3, they show all the recorded values and not a trend line (running average). The graphs demonstrate a diversified character of dispersion of retentive force values for different material combinations. Comparing dispersion values in both groups, they are much lower (20 N) in group 1 as compared to group 2 (40 N). In order to show retentive force stability differentiation between the respective variants, standard deviation values were calculated for every successive 200 cycles (by analogy to the running average – running deviation), and then graphs were drawn presenting the relationship between the number of cycles and standard deviation (Figs. 5a, 5b, 5c).

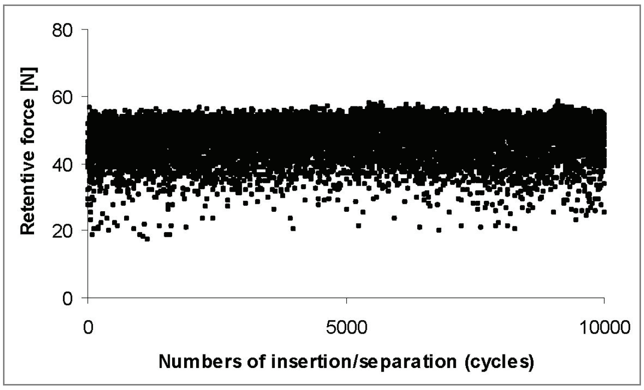

Fig. 4a. Retentive force values measured for chosen single 2° cone angle samples in group 2

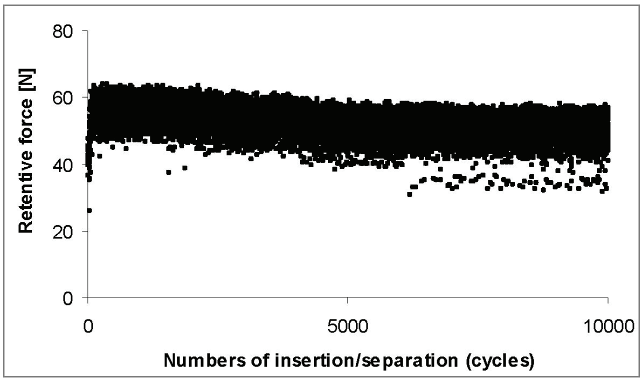

Fig. 4b. Retentive force values measured for chosen single 2° cone angle samples in group 1

Analyzing Figs. 5 it can be assumed that in group 1 with the cone angle 2° values of standard deviation show big variability with the dependence of cycles performed. In the beginning of the test values are about 5 N and decrease to about 3 N. Such values remain stable between 1000 and 6000 cycles. After 6000 cycles values are somewhere between 3.5 and 5 N which is similar to those at the beginning. With the cone angle 4° in group 1 standard deviation values are from 2.7 to 3.8 N till 6000 cycles. After this number of cycles they became more stable and till the end of experiments remained at about 3 N. In group 2 with cone angle 4° standard deviation values are higher

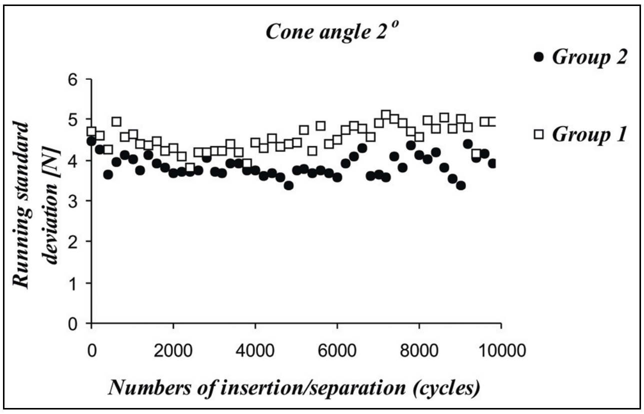

Fig. 5a. Standard deviation (progressive) of retention force (measured for the average of retention forces from 3 repetitions) for 2° cone angle

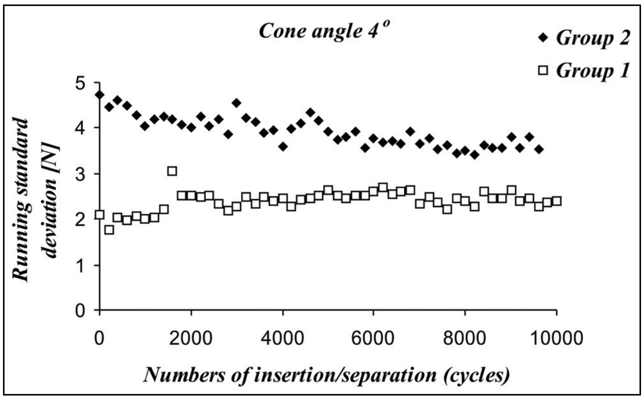

Fig. 5b. Standard deviation (progressive) of retention force (measured for the average of retention forces from 3 repetitions) for 4° cone angle

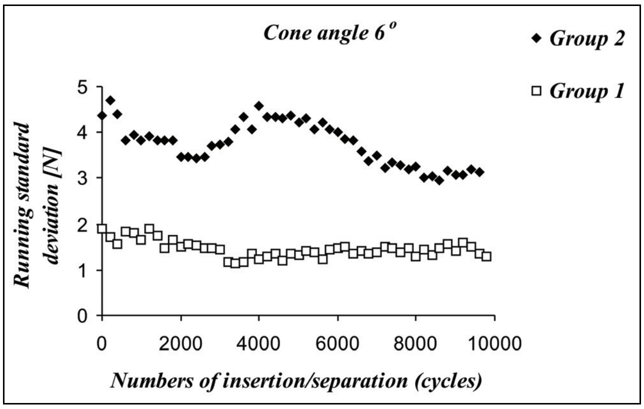

Fig. 5c. Standard deviation (progressive) of retention force (measured for the average of retention forces from 3 repetitions) for 6° cone angle

– from 4 to 6 N. At the cone angle of about 6° there is a clear difference between groups 1 and 2. In group 1, till 2000 cycles values are about 3 N and later on stay on a stable level of 2 N, whereas in group 2 these values are even four times higher (5 to 8 N) throughout the experiment. These findings are more clearly visible in Fig. 6, where the parameter called running standard deviation shows retention force changeability.

4. Discussion

The data obtained in the current study confirm partly previous findings concerning, e.g., the effect of cone angle of the crown on retentive force value. It has been well documented that the retentive force decreases with increasing angle [8], [11], [13]. This is not surprising and has a theoretical support [19]. However, it appears that the strength of this correlation is determined by the type of the material pair (coping fabrication technique). In conditions of the current study, the observations revealed a substantially greater effect of the cone angle on the retentive force (more precisely, on its average value) of the copings cast from the precious alloy, as compared to the pure gold copings made by electroforming. This effect is difficult to explain without additional tests, since the adhesive relationships between the contacting surfaces (as the base for friction resistances during separation of the two denture components) are affected both by elastic properties of materials (Young's modulus) and the type of material used, especially parameters of its crystal lattice [20]. Furthermore, it is worth noting that the oral environment and cyclic character of loading during mastication create favourable conditions for specific frictional interactions to arise. One of those frictional mechanisms is fretting, i.e., a specific type of wear induced under load and in the presence of repeated relative surface micromotion. Microscopic observations of worn orthodontic appliances showed that these oral conditions often create fretting wear [21]. The precision of crown fabrication may also play a role, particularly in the method of electroforming. At the same time, although in most cases the average retentive force value was found to decrease with an increasing number of the loading–unloading cycles, the decrease was considerably milder than that observed by other authors [11], [13]. This seems to be due to the fact that the experiments conducted by the authors cited were performed under dry conditions. Lack of liquid environment that would function as a lubricant could affect the accelerated wear of the contacting surfaces.

As demonstrated earlier, repeatability of retentive force is as essential for normal functioning of the dentures supported by double crowns as its average level. The significance of retentive force stability can be even greater, since with a considerable scatter of its values, there is a significantly increasing probability that too great forces (denture impaction) or too small forces (retention too small to maintain the denture stabilisation) may appear. In this situation, according to Weigl and Lauer [8], the material connections characterized by a lower, yet stable value of retentive force are more favourable than the ones having higher but less stable average retention.

Accurate assessment of stability (repeatability) of retentive force is another problem. On the grounds of significantly varied pattern of changes, it seems that the proposed quantity of the so called running standard deviation reflects relatively well the character of these changes. Owing to such an approach, not only differences in stability between different test variants could be demonstrated but also the fact that retentive force stability may for certain connections change significantly during the experiment (e.g., for electroplated copings with 6° angle – Fig. 5c). To determine the significance of differences in the stability of retentive force between different study variants, this value can be subjected to statistical analysis.

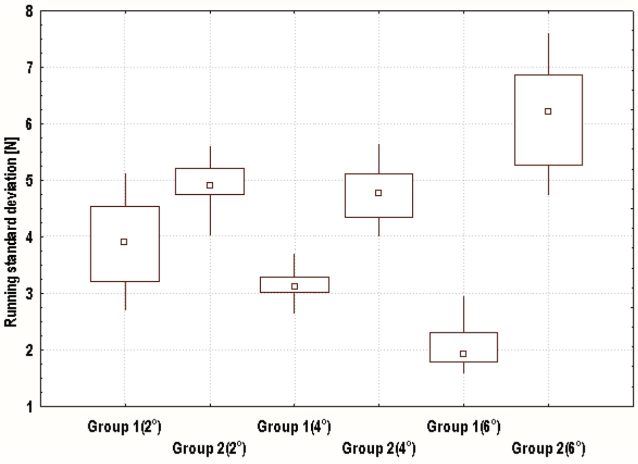

Fig. 6. Box-and-whisker plot for progressive standard deviation: I – min-max, ☐ – 25%–75%, □ – median, respectively

As shown in Fig. 6, the samples tested have a varied retentive force. The relatively high variability of the force observed for the crowns produced by electroplating seems a bit surprising. We are dealing here not only with considerable instability (high median value) but also with its changeable character during experiments (high quartile interval of 25%–75%). Weigl and Lauer reported that retentive force values were very stable in samples in which the primary crowns were made of zirconia ceramics whereas secondary crowns were made by elekctroplating [8]. The explanation of this effect suggested by the authors, relating retentive force stability with precision fit (“made-to-measure”) of the secondary crowns should be considered reliable as well as lack of wedging effect when outer crown is electroformed and no gap is left between occlusal surfaces of crowns. Greater scatter of retentive force values for the electroplated crowns in group 2 (primarily casted) can be due to smaller precision fit associated with casting process itself as compared to casted alloy milled with burs and polished afterwards.

The optimum parameters for retentive force stability were achieved for the samples with 6° cone angle formed by casting. This fact is difficult to interpret, particularly in the context of smaller precision associated with this technology. It seems that also other processes, apart from the adhesive effect, e.g., elastic deformation of the secondary crown, formation of vacuum during crowns separation, rheological properties of artificial saliva or capillary effect may also play a role in this case [7], [8]. On the other hand, the samples with 6° cone angle formed by casting demonstrate the lowest values of retentive force, which seems to be too low for obtaining adequate retention of denture. For obvious reasons, the current study cannot explain all aspects associated with ensuring proper retention in conical double crowns. However, the apparatus designed and the methods suggested offer new possibilities in this field.

Although the mean retention force value was found to be significantly influenced by geometry (cone angle) of the crowns, which confirms the findings reported in literature, the weight of this effect depends also on the materials used for crown making and technology applied [6], [7], [11].

The so called running standard deviation parameter, proposed here, is an effective measure of retentive force stability, allowing not only the assessment of the stability level but also “detecting” any changes throughout the experiment. It should be emphasized that such a procedure can be applied only with the use of a device allowing current recording of retentive force values.

5. Conclusions

In conclusion, within the limitations of current study it can be assumed that:

- the higher the angle value, the lower the average of the retentive force,
- dispersion of retention values is similar in material combination casting alloy/electroforming as compared to casting alloy/casting alloy,

- the conical crown made by the casting method from the precious alloy is better option of both tested in view of its high stability but only with cone angle 6°. When cone angle is 2° or 4° (which is more often used in practice), stability of retention force with the passage of time is higher in combinations with electroformed outer crowns as compared to casted ones.

These conclusions, however, have to be treated with caution as due to relatively considerable dispersion in the results, broader statistical material is needed to formulate ultimate proposals.

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