Comparative Study of Retention of Telescopic Crowns Fabricated by 3D Printing (In Vitro Study)

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Abstract

In combined prosthetics, the retention is performed by friction between the parts of the complex attachments. The appropriate selection of a profile configuration of the two parts is a necessary condition for good retention.

The aim of this study is to examine and compare the retention force of telescopic crowns fabricated with different designs and technologies.

Chrome-cobalt alloy telescopic crowns were fabricated on tooth 26 (Frasaco Typodont A3) by 3D printing (EOS M 100) with a different design (primary telescope height and taper angle), arranged in four groups (1st gr. – classical method, 2nd gr. – FGP methodology, 3rd gr. – USIG-folie system, 4th gr. – method created by the team). Each group included 10 specimens. For all test specimens (n=70), the virtual prototype of the primary and secondary telescope was made on a software program (3-Shape). The specimens from the four groups were subjected to 6,000 cycles of mechanical loading (50N) in artificial saliva. To determine the retention forces, they were subjected to a tensile test on the LMT 100 (LAM Technologies, Italy) apparatus every 500 cycles. For the study, the specialized statistical software IBM SPSS Statistics v.26 was used.

The results of the comparison of the four groups of specimens show a statistically significant difference in retention between the groups. This is due both to the groups' different design and the systems used. The retention force was highest in subgroup "d" of the fourth group, with a taper angle of 0° and a telescope height of 5 mm. The weakest retention force was exhibited by subgroup "a" of the fourth group, as well as by the third group (USIG-Folie).

According to this laboratory study, the group with 0° taper angle and 5mm height of the telescopic crown showed the highest retention force values, indicating that for some methods for producing telescopic crowns – the lower the taper angle, the higher the retention force is.

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Introduction

In combined prosthetics, the retention is performed by friction between the parts of the special, complex attachments. Telescopic crowns – as precision attachments – transmit forces along the longitudinal axis of the abutment teeth and counteract the forces that could displace the removable partial denture. They are used to construct removable dentures commonly used in the treatment and therapy of the dental system (oral cavity) in patients with residual dentition, with periodontal diseases of various intensity[1,2].

The retention force between the primary and secondary telescopes is influenced by the taper angle, the height of the primary telescope, the internal surface roughness, and the tight fit of the two telescopes.

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Telescopic crowns offer periodontal hygiene and function - decisive advantages over other complex attachments[2,3,4,5,6,7,8,9].

Other indicative advantages are the strong retention of the abutment teeth, as well as the integration of a retaining, abutment, counter-reversing function[6,10].

Telescopic dentures fabrication requires very complicated clinical and laboratory procedures. That results in a long treatment period and increased cost. It may be difficult to achieve the exact retention required between the 2 crowns. Also, the retentive force between the crowns decreases after a period of use. That results from the repeated insertion and removal of the denture and the wear of crowns metal[2,3,7,8].

Körber[8] describes in detail the profile design of telescopic crowns. He modified the design of the telescopic crowns, previously introduced by Böttger[10,11,12], into conical crowns with an optimal taper angle of up to 6 degrees, which in its final position achieves effective retention. In the specialized literature, a known modification to improve retention and the problem of friction loss by telescopic crowns is the Marburger Doppelkronensystem[12,13].

Lutzmann[13] introduces a friction fit system [Friktion-Geschiebe-Passung-System] as an alternative to the telescopic crown. Lebedenko[14,15] describes in "Telescopic and locking fasteners dentures" friction elements, representing a combination of spring hemispheres located in the removable part of the denture and slots (corresponding to the hemispheres) in the fixed part of the denture [primary telescope].

Clinical success in dentistry is highly influenced by the materials, techniques, and proper planning. Recently, digital dentistry has been increasingly used in restorative and prosthetic dentistry due to advancements in technologies, like intraoral scanners (IOS) and software[16]. Intensive work in the field of research has been observed since the introduction of the CAD/CAM technology in dentistry[17,18,19]. With the emergence of CAD/CAM technology, telescopic crown attachments can be virtually designed and milled precisely to ensure a passive fit of the attachment parts and maximal function of the RDP[20]. Various materials can be printed from a 3D printer for different applications such as ceramics, polymers, and metals. Commonly used 3D-printed polymers are polylactic acid polyether ether ketone, polyether ketone ketone, poly-glycolic acid, polyurethane, acrylonitrile butadiene styrene, polymethyl methacrylate, polybutylene terephthalate, polycaprolactone, polycarbonates, polyurethanes, etc.[16.]

Since 2000, various tests for the retention of telescopic dentures have been performed – based on either the fabrication technique[14,15,16,17,18,35] or the material with which they have been fabricated[23,24,28]. The main problem associated with telescopic crowns is the loss of retention forces over time, caused by tribiological processes affecting the surface structures of the components[1,3] . Nowadays, methods for the restoration of telescopic crowns' retention exist, however information about them in the specialized literature is limited.

When discussing telescopic crowns as a complex attachment, various fabrication techniques can be considered. Galvanic systems are known for their accuracy but are rarely used due to their high cost. The model casting fabrication method requires experienced dental technicians and a high degree of fabrication-precision to obtain the desired retentive force. Furthermore, it is now possible to fabricate telescopic crowns using CAD/CAM technology[14]. Yet another fabrication method is the Additive Selective Laser Melting (SLM), which when combined with fine finishing in the dental technician's laboratory, results in precise telescopic crowns[18].

It is widely accepted that the retention force between the primary and secondary telescopic crowns should be from 5 to 9N. Many factors affect the retention force, such as the taper angle, conical crown height, saliva, material used, and the surface roughness of conical crowns[16,19,20]. In general, the converging outer surfaces should be with a conicity in the range of 0˚ to 6˚.

The aim of the study is to examine and compare the retention force of telescopic crowns fabricated with different designs and technologies.

Materials and methods

Four groups of test specimens were fabricated by 3D printing, each of which contains the same number of specimens (n = 10).

First group - classical method. The primary telescope is designed with a cylindrical-conical design that meets established standards. The conical part is designed at an angle of 4˚.

Second group - according to the FGP methodology of Bredent, Germany. The methodology includes an auxiliary system for retention between telescopes based on a composite resin. The primary telescope is designed with a cylindrical-conical design, with a taper angle of 4˚.

Third group - according to the Usig-folie methodology of Erkodent, Germany. In order to improve retention, this method uses a composite resin-based auxiliary material between the two telescopes. The design of the telescopic crowns is again cylindrical-conical, with a taper angle of 4˚ (Figure 1).

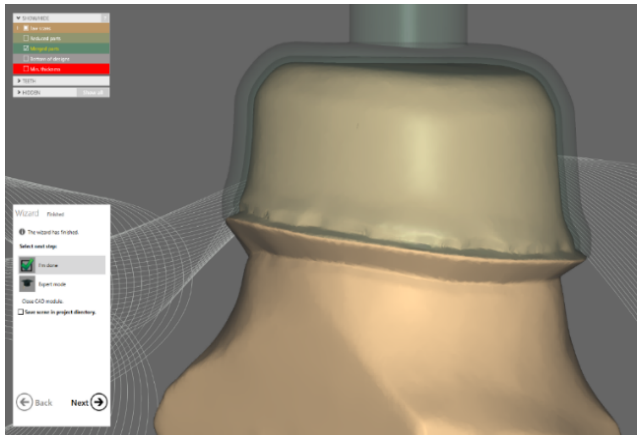

Figure 1. Screen shot of primary and secondary telescope designed with USIG Folie.

Fourth group - the method developed by the author and their scientific team. For this method, there is an additional retentive element on the interproximal wall of the primary telescopic crown - a groove ending in a hemisphere.

Four subgroups were fabricated, differing in the shape of the inner telescope, the height, and the taper angle.

1st subgroup (or group 4a, henceforth) - telescope height 5 mm, cylindrical-conical design, and taper angle 4˚ of the primary telescope (Figure 2).

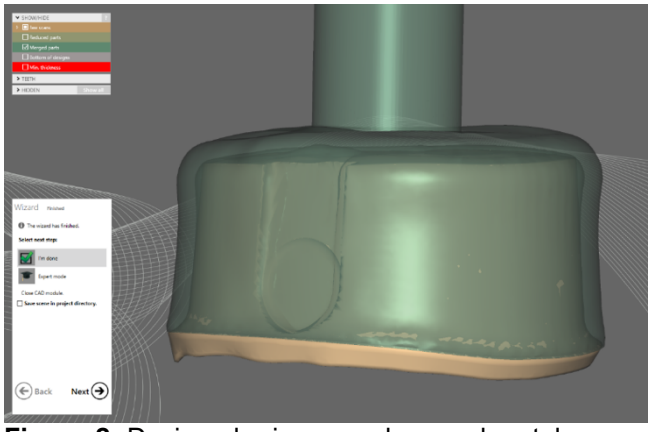

Figure 2. Designed primary and secondary telescope for group 4a.

2nd subgroup (group 4b) - telescope height 6 mm, cylindrical-conical design, and taper angle 2˚
3rd subgroup (group 4c) - telescope height 5 mm, cylindrical-conical design, and taper angle 2˚.
4th subgroup (group 4d) - telescope height 5 mm, cylindrical design (taper angle 0˚).(Figure 3)

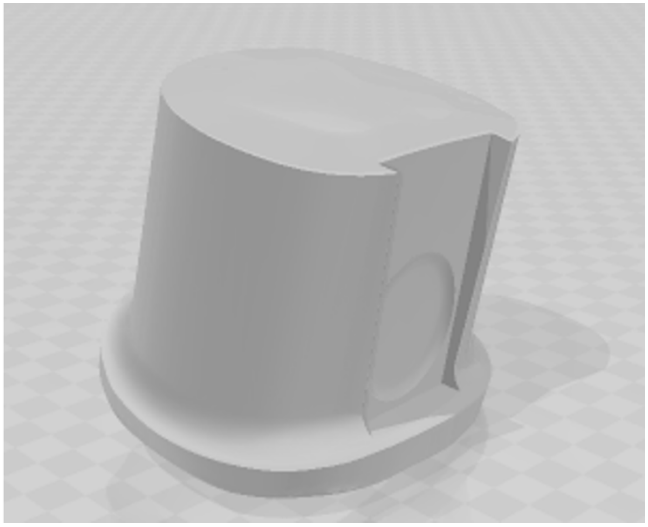

Figure 3. Primary telescopic crown of group 4d.

For all groups, the (II) CAD system was used, which allows the operator to create an electronic model of the image, display it on the screen, and use it to design the denture.

The virtual prototype of the primary and secondary telescopes was made simultaneously on the software program for all test specimens before being printed on the 3D printer (Figure 1, 2). Several parameters were set for all groups:

- 5 mm height of the tooth stump
- sill diameter of 0.6 mm
- minimum thickness of the primary and secondary telescope of 0.5 mm
- distance between the primary and secondary telescope of 10 microns (except for group 4d).

During the creation of the complete virtual prototype of the specimens, an additional retention (10mm long) was set for fixing the specimens to the apparatus.

All obtained specimens were processed according to the same protocol (i.e. sandblasting of the outer surface of the secondary telescopes, as well as polishing with rubber and paste of the primary and secondary telescopic crowns). For the second group, the primary telescopic crowns were polished for one minute on an electropolisher and were subsequently polished to a mirror-smooth surface with rubber and paste.

The third group, using the Using-folie system, consists of a 0.5 mm thick foil, an adhesive system (glue and primer) and a fine filling granulate. The friction increases significantly if the Usig-folie is thermopressed. (Figure 4).

Figure 4. Thermopress-machine – USIG-folie.

In strict compliance with the instructions for operating with the mechanical-cyclic loading apparatus, the additional retentions were cemented on the surface of the primary telescopes with composite material.

In an experimental laboratory setup, developed by the team, the four groups were subjected to a cyclic-mechanical loading of 6,000 cycles of insertion and separation of the elements with a set force of 50 N. The force required to overcome the friction between the primary and secondary

telescopes was measured with the apparatus for testing micro pressure and tension - LMT 100 (Lam technology, Italy) (Figure 5).

The following parameters were set when measuring the retention forces with the LMT 100 apparatus:

- separation speed of 0.1 mm/s
- 1mm of separation path between the primary and secondary telescopes
- distance between retaining elements of 25mm (before the initiation of the separation process)
- loading 50N

To perform the test, custom retaining elements for the apparatus were developed.

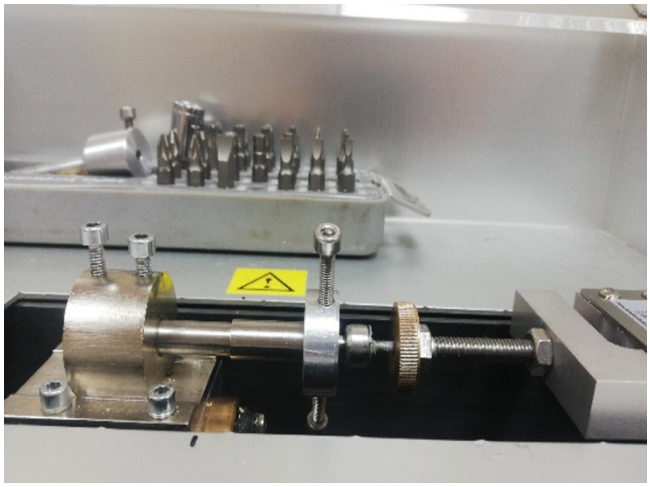

Figure 5. LMT 100 (Italy)- apparatus for testing micro pressure and tension.

CAD/CAM-designed and 3-D printer fabricated test specimens were subjected to a total of 520 mechanical-cyclic loading tests. The retention force was measured before the mechanical-cyclic loading and then every 500 cycles, until a total of either 6,000 or 6500 cycles of cyclic-mechanical loading were performed.

Statistical processing was performed using descriptive, graphical, and correlation analyses and the Wilcoxon-Mann-Whitney and Repeated Measures ANOVA test was utilized for comparison of different groups of specimens. For the purpose of the study, the specialized statistical software IBM SPSS Statistics v.26 was used.

Results

In respect to the first group (i.e., the classical method), the retention is carried out by means of the friction of the metal alloy from which the primary and secondary telescopes are fabricated. The following conclusions can be drawn:

1. The expected force at zero cycles is 2.95 Newton (N).
2. On average, the force can be expected to decrease by about 0.285 N for every thousand cycles (i.e., the relationship between the number of cycles and the retention force is inversely related).
3. In this group, with increasing the number of cycles, the retention force exhibits – besides the aforementioned overall reduction - a variable course (i.e., there are some intermittent jumps in retention force as the number of cycles goes up – see Figure 6 for depiction and comparison of all groups).

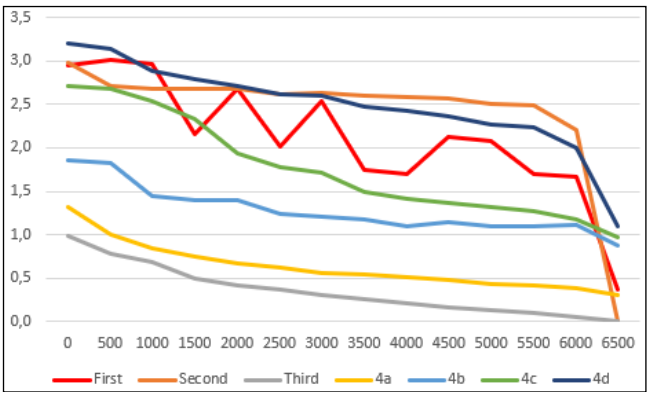

Figure 6. Relationship between the number of cycles and the average retention force in all groups of specimens.

In the second group (FGP system), is applied an auxiliary system for retention between telescopes based on a composite resin**.** The following observations can be made:

1. The expected force at zero cycles is 2.98 N.
2. The force can be expected to decrease by about 0.211 N for every thousand cycles.
3. Overall, this group exhibited the second highest retention force amongst all groups.

In the third group (Usig-folie) is used a composite resin-based auxiliary material between the two telescopes The following conclusions can be drawn:

1. The expected force at zero cycles is 0.99 N.
2. The force can be expected to decrease by about 0.134 N for every thousand cycles.
3. Overall, this group exhibited the weakest retention force from all tested groups.
4. The retention force is significantly lower in comparison to the second group – likely due to the fact that during the insertion and separation of the primary crowns with the secondary telescopic crowns, some surface irregularities are erased, and the retention effect is reduced.

During the fabrication of the specimens of groups 4a, 4b, 4c and 4d, the method of retention developed by the scientific team was applied (with the taper angle and the height of the primary telescope varying). The following observations can be made:

1. The expected force at zero cycles is 1.31 N, 1.86

N, 2.7 N, 3.2 N for groups 4a, 4b, 4c, and 4d, respectively.
2. The force can be expected to decrease by about 0.12 N, 0.12 N, 0.27 N, and 0.23 N for every thousand cycles for groups 4a, 4b, 4c, and 4d, respectively.
3. Amongst all groups, Group 4d (with a taper angle of 0° and 5-mm height of the primary telescope) obtained the highest retention force values.
4. Group 4c (with a taper angle of 2° and 5-mm height of the primary telescope), came fourth in terms of retention force.
5. Groups 4b (with a taper angle of 2° and 6-mm height of the primary telescope) and 4a (with a taper angle of 4° and 5-mm height of the primary telescope) exhibited unsatisfactory retention forces, with only group 3 observing lower retention force among all groups.

For all groups, the relationship between the number of cycles and the force is statistically significant at a 0.01 (1%) risk of error.

The results of the comparison of the four groups of specimens show a statistically significant difference between the groups ($p < 0.001$).

Discussion

The retention forces of double crown prostheses depend on the selected material combination, as well as the fabrication process. The results of the study confirm that the retention forces of double crown prostheses depend on the selected material combination, as well as the fabrication process. In an optimized CAD-CAM process, the milled non-precious metal double crowns showed the highest retention forces with a comparatively continuous retention force behavior during the wear simulation. This may be attributed to a better fit with a consequently narrower joint gap and a comparatively wider occlusal gap between the primary and secondary crowns. Conventionally cast, identical double crowns with a comparable composition of the alloy used showed lower retention forces with a significant loss of retention force[21,22,23].

Based on these results, it can be said that the main drawbacks of the telescopic overdenture are in the complex design and production as well the price of gold alloys. For this reason, the idea of introduction of new materials for double crowns means a potential reduction of the production cost, but above all in digitalization, which reduces the errors caused by the human factor. For example, due to CAD-CAM fabricating, casting beads that are inevitable during conventional casting were avoided. Non-precious metal alloys are convenient because of the much lower price compared to gold alloys but also PEEK and $Zr0_2$[24]. However, literature data and also experience in practice point out that these alloys often cannot reach sufficient retention force and therefore need additional retention elements which complicate more process of production. Also, because of the existence of carbides, oxide layer creation and high elasticity module, double crowns made of non-precious alloys are much more difficult to handle and process. The results from Stancic and Jelenkovic (2008) demonstrate that when a larger number of matrix–patrix components are present as in most cases there is an initial force that is larger than optimal and settling-in phase will last longer, thus providing the possibility of potentially harmful damage to the periodontium over a longer interval[26]. In her study, Aleksandra Lemić conclude that, PEEK telescopic crowns showed higher retentive force values compared to the ZrO2 crowns. The possible explanation may be that known recommendation not to polish inner surfaces of PEEK crowns contributes to an initial high abrasiveness and consequently robust initial retentive force values. In addition to that, PEEK as a flexible material undergoes the process of better adaptation to the primary coping[27]. Assessing the retention forces corresponding to different telescopic systems used in removable prosthetic dentures in her study, Fisher concludes that the retention forces corresponding to the telescopic systems in which the primary crown is made of zirconia registered the highest values, comparing to the ones corresponding to the telescopic systems with Co–Cr primary crowns. Furthermore, the evolution of the retention forces and wear resistance during the 360 cycles (representing the equivalent of one-year usage of the system) is favorable for the zirconia telescopic primary crowns[28]. Moreover, by using zirconia-based ceramic as the material of choice for the development of primary crowns, some limitations, such as unaesthetic aspects that are usually associated with metallic materials, can be overcome. Thus, by using a telescopic system made from zirconia as primary crown and Co-Cr as material for the secondary crown several enhancements can be brought in both aesthetic and functionality terms.

Our studies on the retention force, when using the FGP system (Bredent, Germany), confirm the results of other author teams who had concluded that the retention force in this system is significantly higher [3-7N] compared to the classical method (which relies only on the force of friction[1,30]. Furthermore, researchers studying the relationship between the duration of the load and the retention force, further support the claim that some innovating technologies for fabricating telescopic crowns have higher wear resistance than the classical method [13, 20, 21, 31 & 32, 33]. Yet other authors oppose the supposition that the classical method does not provide high levels of retention [7, 13, 20, 31, 33]. For example, Bayer et al., Beuer et al. and Gurbulak et al. concluded that if the taper

angle is 1° or 2° and the surface of the telescopes is processed according to a certain protocol, the retentiveness in the classical method is very good[7,10,11].

On the other hand, no comparative studies have been published on the effects of FGP and Usig-folie on retention of telescopic crowns. Despite this, some authors have likely identified the reason behind the FGP system's superiority over Usig-folie - For example, in a study on friction in telescopic crowns, Dabrowa et al. proved that the highest coefficient of friction occurs when ceramics are rubbed on FGP composite resin[34] . Overall, there are only a few studies on the Usig-folie system (Erkodent, Germany)[33,34].

In the tested groups, which were based on the method developed by the research team, it was observed that the retention force increases when the taper angle decreases. This statement is similar to others published in the specialized literature [9, 17, 29, 32]. The reason for this is that as the taper angle increases, greater compressive stress is generated (as the primary crown, by occlusal force, acts as a wedge). The mechanism of retention of conical crowns is based on this wedgelike effect.

Especially important for the wear resistance are the shape, taper angle and surface roughness of contacting components. In a study it was stated that friction generally depends on the specific surface roughness (R_a) of the materials (ZrO_2: R_a = 0.02 µm, CoCr: R_a = 0.44 µm) [9,35]. In another study, the galvanic copings yielded a better fit in comparison to casted ones [35]. The reason for this can be the small gap between the functional surfaces of the telescopic crown [35]. The automatic electroplating process achieves a smooth internal coping surface [35] and does not require any manually performed retention load adjustment [34].

Different speeds of separation of the primary from the secondary telescopic crown have been applied in the specialized literature. More specially – Weigl 20 mm/min, Turp1 20 mm/min, Shimakura 5 mm/min, Bayer 120 mm/min and Güngör 0,5 mm/min. As mentioned, in this study, the separation speed was set at 0.1 mm/s (6 mm/min).

In the specialized literature there are different studies that examine the retention of telescopic crowns fabricated with various additional retentive elements. Some of them confirm the results of our study [7, 10, 13, 22, 23, 25, 29, 33, 34]. The authors of other studies applying additional retentive elements concluded that the retention force of the additional retentive element is non-constant force and variable [22, 23]. The reasons for this, in our opinion, lie in various factors - taper angle, material, height of the tooth stump, etc., which could affect retention.

Conclusions

Telescopic crowns create the necessary retention between fixed and moving parts in combined prosthetics [14, 22, 24, 25]. The clinical and laboratory protocol in the process of their fabrication is standardized, and if strictly observed, it leads to successful results[36,37,38,39,40,41,42].

Based on the results of this study, the following can be concluded:

- Retention force depends on the type of technology and is closely related to the adherence to the fabrication process.
- Particularly important for achieving high retention forces and prolonged wear resistance are the usage of an appropriate design (e.g. cylindrical-conical), as well as having as little as possible surface roughness of the contact components.
- When the taper angle between the primary and secondary surface of the crown increases, the compressive force decreases.
- The problem of friction in telescopic crowns – as precision attachments – is complex and requires further research and studies.

Declaration of Interest

The authors report no conflict of interest.

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