Effect of thermo-mechanical dynamic loading on the retention of metallic and non-metallic
telescopic mandibular overdentures

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Abstract:

Purpose: To evaluate the effect of thermomechanical dynamic loading on the retention of
telescopic mandibular overdentures with different metallic and nonmetallic material combinations. Materials and Methods: Four groups were tested: (1) ZP (zirconia abutments/PEEK framework); (2) PP (PEEK abutments/PEEK framework); (3) TP (titanium abutments/PEEK framework); and (4) TG (titanium abutments/gold copings/cobalt-chromium framework). Each specimen contained four implants positioned over a polyvinylchloride-cylindrical base. After 10,000 removal/insertion cycles, the specimens were subjected to thermomechanical dynamic load in a chewing simulator for 1,200,000 loading cycles,
corresponding to 5-year clinical fatigue. A screw was used to receive the chewing load, and 0.5 mm was permitted between the screw and the metal top fixed into the base to simulate the resilience of the posterior residual ridge tissues. Vertical chewing loads of 60 N were applied at a speed of 30 mm/second. Thermocycling was applied with a temperature ranging between 5°C and 55°C. The retentive force was measured using a universal testing machine 10 times before and after the thermomechanical dynamic loading test with a speed of 8 mm/second. **Results:** The mean retentive force increased significantly from 13.2 (± 4.6) N to 16.4 (± 6.1) N in group ZP \((P = .002)\), while in group TP, it decreased significantly from 4.9 (± 2.1) N to 3.3 (± 1.7) N \((P = .046)\). There was no statistically significant change in the retentive force for groups PP and TG. **Conclusions:** The investigated metallic and nonmetallic combinations of double-crown–retained mandibular overdentures maintained acceptable levels of retention after thermomechanical dynamic loading. Further laboratory and clinical studies are needed before their routine clinical use can be recommended. *Int J Prosthodont* 2022. doi: 10.11607/ijp.8014

**Keywords:** Double-crown-retained overdentures; PEEK frameworks; retention; wear; thermomechanical dynamic loading.

1. **Introduction**

There are different factors affecting the retention of double-crown-retained prostheses, such as design-related factors. Examples of these factors are convergence angle of the primary crown and its height, also physical characteristics of the used material, and the impact of surface friction between primary and secondary crowns. The continuous friction between primary and secondary crowns may result in loss of retention due to the wear between both surfaces (1).
Gold alloys are less susceptible to wear and therefore they were considered the gold standard in the fabrication of double-crown-retained prostheses (1, 2). Over the past years, the clinical use of gold is continuously declining primarily due to economic reasons. Furthermore, gold combination with other metals in the oral cavity is limited because of its biocompatibility (3).

In order to find more cost-effective materials with superior bio-compatibility and esthetic properties, both metallic and non-metallic alternatives were investigated, e.g. cobalt-chromium alloys, titanium, zirconia, polyoxymethylene (POM), polyetheretherketone (PEEK), and polyetherketoneketone (PEKK) (4, 5).

Polyetheretherketone (PEEK) is a semi-crystalline thermoplastic polymer. Poly-aromatic ketones have a unique chemical structure that yields stability at high temperatures exceeding 300°C. Additionally, PEEK is easily processed, resistant to radiation damage, chemically stable, and has high stiffness. PEEK could be also combined with many reinforcing agents such as glass or carbon fibers and provide an alternative for patients who have titanium allergy or metal intolerance (6). Regarding biofilm formation, PEEK implant abutments had equal or lower values when compared with zirconia and titanium (7). Therefore, PEEK-based material combinations could be suitable for novel metal-free abutments and the framework of the double-crown-retained overdentures (5, 6).

In a recent publication examining the retention forces of different novel metallic and non-metallic material combinations for double-crown-retained overdentures, acceptable levels of retention were reported. The median retention of test groups ranged from 10.3 to 35 N (8). These levels of retention forces are in agreement with the conclusions of Becker for the telescopic system (9) and Körber for the conical double crowns (10), that a minimum retention force of 3.5
N should achieve adequate denture retention. Likewise, similar levels of retention forces for bar and ball attachments were found to be satisfactory (11).

Furthermore, in a clinical study, it was found that the retention forces ranged from 0.28 N to 64.08 N in different telescopic crowns without reported dysfunction (12). Another clinical study by Stancic and Jelenkovic measured the retention forces of telescopic dentures; they reported retention forces ranging from 1 to 10.7 N (13).

In the aforementioned study of different novel metallic and non-metallic material combinations for double-crown-retained overdentures, the retention force was measured using a chewing simulator with 10,000 insertion/removal cycles (8). The same specimens used in that study were then subjected to thermo-mechanical dynamic loading in order to reveal any effect on the retention.

2. Materials and methods

2.1. Study groups and fabrication of the specimens:

Four groups (n=8) were tested: Group ZP (zirconia abutments/PEEK framework), PP (PEEK abutments/PEEK framework), TP (titanium abutments/PEEK framework), and TG (titanium abutments/gold copings/CoCr framework). Abutments (primary copings) were designed and fabricated using CAD-software/CAM-system. An injection technique was used to fabricate the PEEK frameworks, while the gold copings were electroformed with 0.25 mm thickness. Details of the used materials, specimens’ designs, and abutments’ fabrication as well as the fabrication of secondary crowns have been published previously (8).

2.2. Thermo-mechanical dynamic loading

Following 10,000 insertion/separation cycles on the chewing simulator device, the specimens were then tested for thermo-mechanical dynamic loading. Chewing load simulation was
transferred to the mandible through an acrylic base (Aesthetic Autopolymerisat, Candulor, Zürich, Switzerland), which was constructed over the frameworks extending posteriorly to the area of the molars. The loading point was the expected intersecting point between the extended line between the right and the left first molars and the medial line (14). A screw was used to receive the chewing load; a free space of 0.5 mm was permitted between the bottom of the screw and the metal top fixed into the PVC base. This space simulated the resilience of the residual ridge tissues (Figure 1).

In the chewing simulator device, all specimens were subjected to 1,200,000 chewing simulation cycles, which corresponded approximately to a five-year service time (15). A vertical load of 60 N was applied to the loading point at a speed of 30mm/sec. In addition to the cyclic loading, thermo-cycling was applied with a temperature ranging between 5 °C and 55 °C (Figure 1). To identify the change in retention, the retentive force of each specimen was measured using the universal testing machine 10 times before and after the chewing test while immersed in water. The retentive force of each specimen was measured with a speed of 8 mm/sec after it had been fitted with 50 N axial loading (Figure 1).

2.3. Statistical analysis

Results were reported as means with standard deviations (SD). The Shapiro-Wilk test was used to assess the normal distribution of the data. Paired T-tests were used to compare the retention force before and after the dynamic loading test within each group. Statistical significance level was established at p≤0.05. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp. Armonk, NY, USA).

3. Results
The results of the retention force before and after applying 1,200,000 chewing simulation cycles are summarized in Table 1 and Figure 2. The Shapiro-Wilk test indicated no violation of the assumption of normality. The mean retentive force of group PP was 13.2 (±3.3) N before performing the chewing simulation and 12.2 (±3.4) N afterwards. Regarding group TG, the mean retentive force was 7.1 (±3.6) N and 9.6 (±6.1) N, respectively. There were no statistically significant changes in the retentive force of groups PP and TG (p>0.05). However, there were statistically significant changes in the retentive force of groups ZP and TP after the chewing simulation. It slightly increased from 13.2 (±4.6) N to 16.4 (±6.1) N in group ZP (p=0.002), while in group TP, the mean retentive force decreased minimally from 4.9 (±2.1) N to 3.3 (±1.7) N after the chewing simulation (p=0.046).

4. Discussion

The satisfaction of patients regarding prosthetic restorations is directly depending on durable retention of the prosthesis (16). All attachment systems for overdentures are subjected to wear-related changes resulting in a reduction and/or loss of retention over time. The exact mechanism of wear that inflicts the retentive force of the different attachment systems remains poorly understood. However, it is believed to be multifactorial involving material composition and its wear features, design, dimensions, and the mode of retention of the attachment systems (17). During the long path of using the attachments, the extent of wear plays a crucial role in the durability of retention over time (18).

A double-crown system ensures a stable denture position and the secondary splinting of four implants with telescopic crowns may achieve a better transfer of retentive forces to the individual fixtures crowns/implants compared to the primary splinting with rigid or jointed bar attachments (19).
Wagner et al. and Merk et al. identified some limitations in their studies concerning simulating the oral environment conditions, as cyclic fatigue loading. Which could significantly weaken the retention load of the telescopic crowns. In addition, they did not simulate any thermodynamic loading in their studies (4, 20). In the present study, the thermo-mechanical dynamic loading test aimed to analyze the changes of retention force of telescopic overdenture after dynamic loading conditions simulating the rotational movement of implant-supported overdenture with thermocycling in temperature ranging between 5 °C and 55 °C (14).

The specimens were subjected to a dynamic loading for 1,200,000 chewing cycles, which corresponds approximately to 5 years of clinical service (15). In a clinical study, that analyzed the function of the masticatory system in patients wearing implant-supported overdentures, three bite-force levels were reported. The mean value for gentle biting was 15.7 N, while the mean chewing force was 50.1 N and the maximum bite force was 144.4 N (21). In the present study, a vertical load of 60 N was applied on the loading point at a speed of 30 mm/sec as used by other studies (14, 22), that was applied during the chewing simulation test which allowed the bottom of the screw to touch the metal top fixed to the PVC base.

Before and after the thermo-mechanical dynamic loading test, the retentive force of each specimen was measured 10 times using the universal testing machine with a 50 N repeated load and a speed of 8 mm/sec. This approach is in agreement with other studies which repeated a similar measurement technique 10 times to prevent any coincidence of results (1, 23, 24).

After the thermo-mechanical dynamic loading test, there were no statistically significant changes in the retentive forces of groups PP and TG. On the contrary, there was a statistically significant increase in the retentive force of group ZP and a statistically significant decrease in the retentive force of group TP. The observed results could be attributed to the different physical
properties and extent of wear of the different tested materials as well as to the possible difference in material mechanical adaptation. Moreover, these changes in the retentive forces seem minimal and not clinically relevant.

The extent of wear resulting from the relative movement between the surfaces of the copings may be minimal or pronounced, this is determined accordingly if the elevations of the surface are leveled or broken off. The nature of resulting wear will subsequently have an impact on the retentive force. Typically, the wear results in replacing the firmly wedged contact with a space and thus decreasing the retentive force. However, if the wear-marks interlock, the retentive force may increase over time. Occasionally, the effect of the wear remains minimal and as a result the retentive force remains stable (24). Also, Besimo et al. reported increased retentive forces of different metallic combinations of gold, titanium, and CoCr for inner and outer crowns after 10,000 insertion and separation cycles. They attributed the results to the possible mechanical surface adaptation between the inner and the outer crowns (25).

The results of the present study agree with the results reported in our previous study (8). Both reports confirm possible durable levels of retention of different test groups. Which might be encouraging for further laboratory and clinical investigations.

5. Conclusion

The investigated metallic and non-metallic combinations of double-crown-retained mandibular overdentures maintained acceptable levels of retention after thermo-mechanical dynamic loading. Further laboratory and clinical studies are needed before their routine clinical use can be recommended.

6. Acknowledgment
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7. Conflict of Interest

The authors have no conflict of interest.

8. References:

Table

Table 1: Means and standard deviations of the retention force in N before and after performing the thermo-mechanical dynamic loading

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<thead>
<tr>
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<th>Mean retentive force in N (±SD)</th>
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<td>ZP</td>
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<td>Before the thermo-mechanical</td>
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<td>dynamic loading</td>
<td>13.2 (±4.6)</td>
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<tr>
<td>After the thermo-mechanical</td>
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<tr>
<td>dynamic loading</td>
<td>16.4 (±6.1)</td>
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N=newton; SD=standard deviation; ZP=zirconia/PEEK; PP=PEEK/PEEK; TP=titanium/PEEK; TG=titanium/gold/CoCr.

Figure legends

Figure 1.  
a: Preparation of a test specimen for the chewing simulation;  
b: A free space of 0.5 mm was permitted between the bottom of the screw and the metal top fixed into the PVC base;  
c: A model fixed in the universal testing machine;  
d: A model fixed in the chewing simulator device.

Figure 2. Box-plot representing the retention force in N before and after performing the thermodynamic loading test.