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Double-Crown Prosthesis Retention using Polyetherketoneketone (PEKK): An In Vitro Study

Running title: PEEK Telescopic Crown Retention Force

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Abstract

Purpose: To assess the retentive force of telescopic crowns using polyetherketoneketone (PEKK) high-performance polymer (HPP) in relation to conventional materials over a long period of time in an in vitro setting.

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Materials and Methods: Thirty-six sets of primary and secondary crowns were fabricated as per the double crown-retained prostheses approach. Six samples were included in each of the five test groups (1: Zirconia/PEKK [Zr/PEKK]; 2: Titanium/PEKK [Ti/PEKK]; 3: Cobalt-chrome/PEKK [CoCr/PEKK]; 4: PEKK/PEKK; 5: Gold/PEKK [Au/PEKK]) and the single control group (Gold/Galvano-gold [Au/GA]). The insertion-removal test was performed for 20,000 cycles, and the surface condition was observed. Retentive forces were analyzed using two-way ANOVA ($\alpha<0.05$).

Results: The retention forces in groups Zr/PEKK and Ti/PEKK significantly decreased over time (group 1: p=0.035, group 2: p=0.001), whereas retentive force increased significantly in groups PEKK/PEKK, Au/PEKK, and Control (group 4: p=0.001, group 5: p=0.008, control: p=0.042). Similar wear was observed on the primary crown in groups PEKK/PEKK, Gold/PEKK, and control.

Conclusions: Groups PEKK/PEKK and Au/PEKK showed a transition of retentive force similar to the control group. Groups PEKK/PEKK and Au/PEKK had similar wear on the surface compared to control. Therefore, PEKK has a promising clinical potential.

Keywords

Double crowns; PEKK**;** Ketones; Gold; Chromium Alloys; Prosthesis Retention; Retentive force; Telescopic crowns.

Partially edentulous patients with a reduced number of remaining teeth or fully edentulous patients with strategically placed implants can have their original occlusion restored successfully with partial removable dental prostheses (RDPs) or overdentures (ODs), which can be retained using the double crown system.[1,2] Double crowns are an effective retainer that can support and rigidly connect multiple abutment teeth or implants by transmitting occlusal forces along the vertical axes of the abutments.[3-5]

Implant-ODs (IODs) use a variety of attachment systems. Rigidly connected attachment systems include bar attachments, while the independent attachment systems comprise spherical/ball-types, magnets, telescopic crowns, or stud-type attachments.[6,7] The success of overdentures

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primarily depends on the retentive capacity of its attachment element to sustain its long-term functionality.[8] Micro- and macro-movement between the retentive surfaces of an attachment system during mastication and removal of the OD may lead to wear and diminish retentive forces over time.[9] Normally, the combination of materials in overdenture attachments comprises a metal-metal, zirconia-metal, or metal-polymer contact.[9,10] Therefore, differences regarding surface wear and resistance to repetitive removal-insertion cycles might be found.

Telescopic attachment types are specific hybrid compositions of fixed abutments (i.e. primary inner crowns) and removable prostheses (i.e. secondary outer frameworks).[11] Depending on the retention mechanism, double crown-retained removable dental prostheses (RDP) can be classified into three subgroups: parallel-walled telescopic crowns, conical double crowns, and double crowns with additional retention modifications.[12] The fabrication of telescopic RDPs is highly demanding, and special skills are required of both the dental technician and the clinician, which consequently increases the total cost of the double crown prosthesis. Traditional materials used for the inner and outer crowns are gold-alloys and cobalt-chromium (CoCr) metal-alloys. With the introduction of computer-aided design and computer-aided manufacturing (CAD-CAM) technologies, inner- and outer-crowns, as well as the tertiary frameworks, are increasingly produced by precision milling.[13] Traditional materials like gold-alloys seem to be beyond the scope due to their high cost.

Recently, a high-performance polymer material has been introduced for provisional and definitive dental reconstructions.[14,15] Polyetherketoneketone (PEKK) is an amorphous or crystalline thermoplastic with high strength, rigidity, and resistance to hydrolysis that does not show any porosities or remaining monomers. Moreover, it is only the form and not the chemical property that is altered during the processing of PEKK.

Pekkton ivory (PEKK; C+M Cendres + Metaux, Biel, Switzerland) displays both amorphous and crystalline material characteristics.[16] In its crystalline form, it can be milled and used in digital workflows, which will help to reduce human labor and, thereby, cost. Consequently, PEKK can also be considered as material for RDPs or overdentures.[17] However, scientific analysis of the best material combination for a primary telescopic crown and the corresponding secondary framework material is still unavailable.

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The null hypothesis was that the retentive forces of primary crowns made of various materials, including PEKK and secondary crowns made of PEKK, would be equal to that of the gold standard, Gold (primary crown)/Galvano gold (secondary crown) after 20,000 connection and disconnection cycles. This in vitro investigation aimed to assess milled PEKK as an alternative material for double crown prostheses.

Materials and methods

Five test groups and one control group (Fig 1) were predetermined for examining the retentive force and long-term effects on single-unit primary/inner-secondary/outer combinations. Thirty-six artificial Typodont (A55AN-131, Nissin, Tokyo, Japan) maxillary canines were prepared for a full crown design with deep chamfer of 1.0 mm width. The prepared teeth were designed with the following dimensions: 8.0 mm buccal height, 2.5 mm lingual height, 8.0 mm buccolingual width, and 7.0 mm mesiodistal width (Fig 2).

A total of 36 primary crowns were fabricated for the five test groups and one control group in this study: Zirconia (Zr; group 1; DD Bio ZX[2], Dental Direkt, Spenge, Germany), Titanium (Ti; group 2; KZR-CAD Ti, Yamakin, Osaka, Japan), CoCr (group 3; KM-Cobalt Chrome, Kyocera, Kyoto, Japan), PEKK (group 4; Pekkton®, C+M Cendres + Metaux, Biel, Switzerland) and Gold (Au; both group 5 and control, Cast Master Gold, IDS, Tokyo, Japan). Six crowns were fabricated in each group. The shape of the primary crowns was designed by the CAD-CAM system (D2000 scanner, 3shape, Denmark) to be the same design. From groups 1 to 4, primary crowns were milled from milling blanks, whereas wax patterns were milled and cast in the group using Au. Primary inner crowns were prepared to be 2 degrees for axial taper.[3] The friction heights of buccal and lingual were prepared to be 5.0 mm and 3.0 mm, respectively.[4] The thickness of the primary inner crowns was 0.6 mm. The secondary crowns for all test groups were made of PEKK. The PEKK samples were milled to have a 25 µm space between primary and secondary crowns. The secondary crown for the control group used the Galvano-gold (GA; AGC® Speed gold electrolyte 99.99%, C. Hafner GmbH, Wimsheim, Germany). Galvano-gold (GA) samples for the control group were made by a dental technician, working at a private dental laboratory, who has experience with double crowns.

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The primary crowns were cemented to the artificial typodont (Fig 2) using phosphate modified resin cement (Panavia F2.0, Kuraray Noritake, Tokyo, Japan) according to the method of Fuhrmann et al.[16] The secondary crowns were cemented into the CoCr cap (Fig 3) using the same resin cement as the primary crown. All the primary inner crowns cemented on the typodont, and secondary crowns cemented into the CoCr cap, were embedded into polyvinyl chloride models of uniform dimensions.

The tests were carried out with a linear-torsion all-electric dynamic test instrument (EMT-1KNV-30, Shimadzu Corp., Kyoto, Japan). The testing cycles were performed under wet conditions using artificial saliva (5 mL, Saliveht Aerosol, Teijin Pharma Ltd., Tokyo, Japan) in a custom fabricated trough. The testing machine was programmed to seat the secondary crown on the primary crown with a force of 50 Ncm for one second[18] followed by a removal cycle with a frequency at 1 Hz.[19] The data for the first 100 cycles (referred to in this study as “baseline”) were omitted to stabilize the testing device, as the testing device provides multiple force readings per testing cycle. The retentive force (Ncm), which is used for further analysis, represents the absolute value of the force vector of the removal movement (absolute difference between initial and final force readings of the removal cycle). For analysis, the results are considered in cycles of 500, 1000, 2000, 5000, 10,000, 15,000 and 20,000. The number of cycles assigned experimentally simulates 13 years of intraoral function with a stipulated number of four insertion-removal cycles per day.[19]

Changes in the surface structure of the primary/inner crown were observed using an S-800 Hitachi stereoscopic electron microscope (SEM; Hitachi High-Technologies Co, Tokyo, Japan) to assess the condition of the surface of primary/inner crowns before and after testing. For statistical analysis, when the effect size (partial η^2) of the interaction between insertion-removal cycles and test groups was 0.1, the required sample size was calculated as a study design that can detect statistical significance ($\alpha = 0.05$, $\beta = 0.8$). At this time, a total of 24 samples had the required sample size, and 4 samples in each group had the minimum required sample size. Power analysis was conducted for the effect size because specific estimates of the mean and standard deviation were not available from previous studies. Partial $\eta^2 = 0.1$ was set as a medium effect size. Considering variance errors in the data, the sample size was set to 6 in each group. To compare the resistance transition with the number of insertions and removals between the tested telescopic crowns, two-way repeated-measures ANOVA was performed with resistance as the dependent variable, the insertion and

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removal cycles as the intra-subject effect, and tested group combinations as the inter-subject effect. This model includes an interaction term between the number of attachments and detachments and materials tested. Correction with Benjamini and Hochberg methods[20] was used for the pairwise comparison between the materials tested in the telescopic groups at each insertion-removal cycle and pairwise comparisons between the insertion-removal cycles in each group of double prostheses. A standard level of significance was set at alpha <.05.

Results

All the samples completed the 20,000 insertion-removal cycles. No fractures or decementations were observed during the testing. Retentive force was used as the dependent variable, and the number of test cycles (Time) was used as the test of within-subject effect. Two-way repeated measures ANOVA including the interaction term was performed with five test groups and one control group (Test) as the effect between subjects. Supplemental Table 1 confirms that the Time*Test interaction term is significant ($p < 0.001$). Therefore, it was confirmed by Test that there is a difference between the test materials in the transition of the retentive force depending on the number of test cycles. The results of the retentive force in each cycle are shown in Figure 4. At the beginning of the insertion-removal test, significant differences were found between the groups; [Zr/PEKK vs. control: $p<0.0001$], [Ti/PEKK vs. control: $p<0.0001$], [CoCr/PEKK vs. control: $p<0.0001$], [Zr/PEKK vs. PEKK/PEKK; $p<0.0001$], [Zr/PEKK vs. group 5: $p=0.01$], [Ti/PEKK vs. PEKK/PEKK; $p<0.0001$], [Ti/PEKK vs Au/PEKK; $p<0.0001$], [CoCr/PEKK vs PEKK/PEKK; $p<0.0001$], [CoCr/PEKK vs Au/PEKK; $p<0.0001$]. At 2000, 5000, and 10000 cycles, the only significant differences that appeared were between groups Zr/PEKK and CoCr/PEKK: [$p=0.002$ at the 2,000 cycles], [$p=0.025$ at 5,000 cycles], [$p=0.006$ at 10,000 cycles]. In terms of retention differences, after 15,000 cycles there were no significant differences among the groups.

The results of the differences in the retentive force compared to the baseline for each cycle are shown in Table 1. At the end of the tests, groups Zr/PEKK and Ti/PEKK significantly decreased in retentive force (Test 1: $p=0.035$, Test 2: $p=0.01$), whereas groups PEKK/PEKK, Au/PEKK, and control significantly increased in retentive force (Test 4: $p=0.001$, Test 5: $p=0.008$, Control: $p=0.042$).

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CoCr/PEKK increased in retentive force until it reached 5,000 cycles. Then, it decreased in retentive force, so, overall, no significant differences were registered.

Figure 5 shows the primary crown surfaces before and after the insertion-removal tests. All the specimens incurred damage on the primary crown surface after the 20,000 cycles of insertion-removal tests. Although groups PEKK/PEKK, Au/PEKK, and control displayed similar damage on the surface, test group Zr/PEKK showed the least amount of damage to the surface of the primary crowns.

Discussion

The present study evaluated the retentive force of several material combinations between primary and secondary crowns for the double crown system in a wet environment, simulating 13 years of use. It was intended to compare the retentive forces of double crowns using common materials such as Zr, Ti, CoCr, Au, and GA, as well as including PEKK as a new material. Since prostheses using CAD-CAM technology are increasing in dentistry, several material combinations were compared against one another to determine the retentive force of double crowns and the wear of the surfaces of primary crowns at different insertion and removal cycles. Based on the present study, the null hypothesis of equal retentive forces compared to the control was rejected. Statistical differences in the retentive forces were found among the groups. Moreover, the tendency toward damage of the surface of the secondary crowns could be observed by SEM.

Before the implementation of CAD-CAM technology, primary and secondary crowns were cast by dental technicians using the lost wax technique.[21] Primary and secondary crowns were fabricated using Au, because of the stability and ease of processing, although casting crowns introduced errors. Therefore, a tooth loss of up to 32% at 10 years has been observed in double crowns.[22] A retrospective study of partial RDPs using double crowns reported a 10-year survival rate of 94.7%.[23] However, prosthetic tooth wear (6.3%) was the third most common reason for the failure of double crown prostheses. Another article reported different classifications of the remaining tooth

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position and its influence on the survival rate of the abutment teeth.[24] Also, the technical complication of loosening from friction was mentioned. Our in vitro study assessed single teeth. Therefore, an in vitro study using prostheses on multiple artificial teeth is needed in the future.

PEKK has a similar compressive strength to tooth dentine.[16] Therefore, PEKK has strong potential as an alternative material to metal. It was shown that PEKK/PEKK and Au/PEKK combinations in our study offered higher retentive force than that of the conventional control group (Fig 4). Comparing the retentive force transition among the tested groups, PEKK/PEKK and Au/PEKK combinations gradually increased from the initial test, and PEKK/PEKK showed the highest retentive force of all the groups tested by the final test. Thus, the lower cost, stability, and better retention force of PEKK may make it an excellent alternative to precious metals for double crowns. Moreover, PEKK shows a lower specific gravity than Au, and PEKK acts as a shock absorber.[16,25] Kotthaus et al conducted an in vitro study including PEKK for the double crown, and it showed acceptable outcomes.[25] However, that report did not include Au/GA as the traditional combination in the assessment. The present study included an Au/GA group as a control group, and PEKK yielded more stable data than the Au/GA combination. Therefore, our study confirmed that PEKK could be an alternative material to metal components.

Ti/PEKK, CoCr/PEKK, and Zr/PEKK showed a higher retentive force in the initial test. The Ti/PEKK group increased and had the highest retentive force for up to 500 cycles. However, Ti/PEKK gradually decreased in retentive force until it ended up as the second lowest value. A titanium surface is stable because it oxidizes easily.[26] However, when titanium alloys run into friction with most metals or ceramics, the surface of titanium alloys produces severe adhesive wear.[27,28] The damaged surface of the titanium primary crown surface confirmed the issue with severe wear (Fig 5). Moreover, since all specimens were immersed in artificial saliva, the specimens were subjected to more strict and realistic conditions than a dry environment. Schimmel et al observed the retentive force of telescopic crowns using basically the same materials as the present study.[29] This study used the PEEK instead of PEKK and reported that the Ti (primary crown)/PEEK (secondary crown) combination showed the best results for retentive force. This may result from the lower compressive strength of PEEK compared to PEKK[16,30], which may have resulted in less wear of the primary crown. Moreover, this study used Au as the primary and secondary crown for the control group. The present study used GA

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as the secondary crown for the control group. Therefore, the tendency when comparing materials with the control group seems a little different in the two studies. The retentive force of the CoCr/PEKK group decreased at 10,000 cycles. However, there were no significant differences between the baseline and the last retentive force test. Additionally, the CoCr/PEKK group had the best retentive force of all tested groups after 20,000 insertion-removal cycles. CoCr has high strength[31] and is relatively light; consequently, it is commonly used in dentistry, especially for RDP frameworks/substructures. However, CoCr may cause abrasion after some years in use (6.5 simulated years) as the retentive force decreased at 10,000 cycles. CoCr pieces from abrasion might induce allergies.[32] In the Zr/PEKK group, the retentive force continuously decreased test after test. zirconia has the highest strength and hardness of all dental materials, but the least flexibility.[33] The hardness of zirconium may propitiate abrasion and lost retention force.

Some papers have investigated double crowns in in vitro studies using zirconia as the primary crown.[34-36] The retentive force between gold and zirconia primary crowns was compared using electroplated gold secondary crowns.[34] Zirconia primary crowns showed a stable low retentive force compared to the present study. However, gold primary crowns increased the retentive force, same as in this study. Therefore, an Au/GA combination may increase the retentive force due to gold properties. An important difference is that Turp et al[35] set three different conus angles of the primary crowns, and the retentive force changed due to the taper angle. In the present study, the conus angle was set at 2 degrees, and it showed the lowest value of retentive force. Using zirconia as primary crown showed consideration of the taper of the angles. Another study used zirconia primary crowns coupled with zirconia and electroformed Au and PEEK secondary crowns.[36] This experiment showed the same tendency in both groups; however, the retentive force was lower than in the present study. The space between the primary and secondary crown might be influenced by the milling strategy or post-processing protocol, as the present study showed a different tendency and a high retentive force. Therefore, the space between the primary and secondary crown needs to be considered.

Regarding the retentive force differences between the baseline and the end of the insertion-removal test, PEKK/PEKK and Au/PEKK groups displayed a significantly higher value compared to the other groups. Thus, it could be assumed that PEKK can be an alternative material for Au when conducting telescopic reconstructions. PEKK prostheses are fabricated with CAD-CAM technology,

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decreasing both the dental laboratory costs and casting errors. Hence, it might be better to use PEKK for the double crown technique. Although the same space between primary and secondary crown was set for all groups at the baseline, the retentive force was significantly different among the groups. Indeed, this can be explained by the mechanical properties (i.e., elastic modulus, Vickers hardness, and toughness) of the tested materials being different among the groups tested. Further investigation may be needed to determine the optimal space and design, combining several materials for the double crown-retained prosthesis.

Regarding the simulated intraoral stability of the tested materials, PEKK or Au can be an alternative material, equivalent to the Au/GA combination, for double crown prostheses. The results may suggest that PEKK is a promising material for custom abutments used in tooth-borne fixed dental prostheses (FDPs) and IODs scenarios. However, in implant dentistry, PEKK has only been used as temporary abutments. Therefore, the use of PEKK as an implant-supported primary crown would rather be conceivable in a titanium base (Ti-base) concept, in which the primary crown is bonded extraorally to the Ti-base.[37] Additionally, despite individual studies have shown that sufficient adhesive bonding between PEKK and tooth surfaces is feasible,[37,38] a scientific consensus for PEKK bonding procedures is lacking. This lack of clarity entails a certain risk of complications when using PEKK as primary crowns. Another clinically critical issue is accuracy in the milling of PEKK, and the resulting marginal integrity.[39, 40] The available data regarding the marginal integrity of copings[41] and frameworks[39] deemed PEKK within the clinically acceptable range (< 90 μm). Moreover, the retentive forces were different among the groups despite the same space between primary and secondary crowns. Additional in vitro studies may be required to discover the optimal space of various material combinations for double crown-retained prostheses.

Conclusions

The PEKK/PEKK and Au/PEKK primary/secondary-crown combinations were superior in retention force performance compared with the Au/GA combination. The CoCr/PEKK group combination presented stable retention during the tests and the highest retentive force after a total of 20,000

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insertion/removal cycles. Since PEKK/PEKK and Au/PEKK displayed similar surface wear to the control group, PEKK has a promising clinical potential.

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References

1. Verma R, Joda T, Brägger U, et al: A systematic review of the clinical performance of tooth-retained and implant-retained double crown prostheses with a follow-up of ≥ 3 years. J Prosthodont 2013;22:2-12

2. Bohnenkamp DM: Removable partial dentures: clinical concepts. Dent Clin North Am 2014;58:69-89

3. Groesser J, Sachs C, Heiss P, et al: Retention forces of 14-unit zirconia telescopic prostheses with six double crowns made from zirconia--an in vitro study. Clin Oral Investig 2014;18:1173-1179

4. Schwindling FS, Stober T, Rustemeier R, et al: Retention behavior of double-crown attachments with zirconia primary and secondary crowns. Dent Mater 2016;32:695-702

5. Breitman JB, Nakamura S, Freedman AL, et al: Telescopic retainers: an old or new solution? A second chance to have normal dental function. J Prosthodont 2012;21:79-83

6. Trakas T, Michalakis K, Kang K, et al: Attachment systems for implant retained overdentures: a literature review. Implant Dent 2006;15:24-34

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7. Leão RS, Moraes SLD, Vasconcelos BCE, et al: Splinted and unsplinted overdenture attachment systems: A systematic review and meta-analysis. J Oral Rehabil 2018;45:647-656

8. Sadowsky SJ, Zitzmann NU: Protocols for the maxillary implant overdenture: A systematic review. Int J Oral Maxillofac Implants 2016;31 Suppl:s182-191

9. Kang TY, Kim JH, Kim KM, et al: In vitro effects of cyclic dislodgement on retentive properties of various titanium-based dental implant overdentures attachment system. Materials (Basel) 2019;12

10. Rinke S, Buergers R, Ziebolz D, et al: Clinical outcome of double crown-retained implant overdentures with zirconia primary crowns. J Adv Prosthodont 2015;7:329-337

11. Hakkoum MA, Wazir G: Telescopic denture. The open dentistry journal 2018;12:246-254

12. Arnold C, Hey J, Setz JM, et al: Retention force of removable partial dentures with different double crowns. Clin Oral Investig 2018;22:1641-1649

13. Bergler M, Holst S, Blatz MB, et al: CAD/CAM and telescopic technology: design options for implant-supported overdentures. Eur J Esthet Dent 2008;3:66-88

14. Wachtel A, Zimmermann T, Sütel M, et al: Bacterial leakage and bending moments of screw-retained, composite-veneered PEEK implant crowns. J Mech Behav Biomed Mater 2019;91:32-37

15. Wagner C, Stock V, Merk S, et al: Retention load of telescopic crowns with different taper angles between cobalt-chromium and polyetheretherketone made with three different manufacturing processes examined by pull-off test. J Prosthodont 2018;27:162-168

16. Fuhrmann G, Steiner M, Freitag-Wolf S, et al: Resin bonding to three types of polyaryletherketones (PAEKs)-durability and influence of surface conditioning. Dent Mater 2014;30:357-363

17. Gentz FI, Brooks DI, Liacouras PC, et al: Retentive forces of removable partial denture clasp assemblies made from polyaryletherketone and cobalt-chromium: a comparative study. J Prosthodont 2021; doi:10.1111/jopr.13398.

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18. Shimakura M, Nagata T, Takeuchi M, et al: Retentive force of pure titanium konus telescope crowns fabricated using CAD/CAM system. Dent Mater J 2008;27:211-215

19. Kobayashi M, Srinivasan M, Ammann P, et al: Effects of in vitro cyclic dislodging on retentive force and removal torque of three overdenture attachment systems. Clin Oral Implants Res 2014;25:426-434

20. Benjamini YaH Y: Controlling the false discovery rate: A practical and powerful approach tomultiple testing. J R Statist Soc B 1995;57:289-300

21. Langer A: Telescope retainers and their clinical application. J Prosthet Dent 1980;44:516-522

22. Moldovan O, Rudolph H, Luthardt RG: Biological complications of removable dental prostheses in the moderately reduced dentition: a systematic literature review. Clin Oral Investig 2018;22:2439-2461

23. Yoshino K, Ito K, Kuroda M, et al: Survival rate of removable partial dentures with complete arch reconstruction using double crowns: a retrospective study. Clin Oral Investig 2020;24:1543-1549

24. Hinz S, Schweyen R, Hey J, et al: Clinical performance of non-precious metal double crowns with friction pins in severely reduced dentitions. Clin Oral Investig 2020;24:3567-3575

25. Kotthaus M, Hasan I, Keilig L, et al: Investigation of the retention forces of secondary telescopic crowns made from Pekkton® ivory in combination with primary crowns made from four different dental alloys: an in vitro study. Biomed Tech (Berl) 2019;64:555-562

26. Wang RR, Fung KK: Oxidation behavior of surface-modified titanium for titanium-ceramic restorations. J Prosthet Dent 1997;77:423-434

27. Shi X ZW, Wang M, Xu Z, et al: Tribological performance of Ni3Al–15 wt% Ti3SiC2 composites against Al2O3, Si3N4 and WC-6Co from 25 to 800 °C. Wear 2013;303:244-254

28. Niu Q ZX, Chen M, Ming W: Study on the tribological properties of titanium alloys sliding against WC-Co during the dry friction. Industrial Lubrication and Tribology 2014;66:202-208

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Accepted Article

29. Schimmel M, Walther M, Al-Haj Husain N, et al: Retention forces between primary and secondary CAD/CAM manufactured telescopic crowns: an in vitro comparison of common material combinations. Clin Oral Investig 2021;25:6297–6307

30. Villefort RF, Diamantino PJS, von Zeidler SLV, et al: Mechanical response of PEKK and PEEK as frameworks for implant-supported full-arch fixed dental prosthesis: 3D finite element analysis. Eur J Dent 2021;doi:10.1055/s-0041-1731833.

31. Duong CT, Nam JS, Seo EM, et al: Tribological property of the cobalt-chromium femoral head with different regions of wear in total hip arthroplasty. Proc Inst Mech Eng H 2010;224:541-549

32. Cavelier C, Foussereau J, Gille P, et al: Allergy to nickel or cobalt: tolerance to nickel and cobalt samples in man and in the guinea pig allergic or sensitized to these metals. Contact dermatitis 1989;21:72-78

33. Zhang Y, Lawn BR: Novel zirconia materials in dentistry. J Dent Res 2018;97:140-147

34. Bayer S, Kraus D, Keilig L, et al: Changes in retention force with electroplated copings on conical crowns: a comparison of gold and zirconia primary crowns. Int J Oral Maxillofac Implants 2012;27:577-585

35. Turp I, Bozdağ E, Sünbüloğlu E, et al: Retention and surface changes of zirconia primary crowns with secondary crowns of different materials. Clin Oral Investig 2014;18:2023-2035

36. Schubert O, Reitmaier J, Schweiger J, et al: Retentive force of PEEK secondary crowns on zirconia primary crowns over time. Clin Oral Investig 2019;23:2331-2338

37. Gama LT, Duque TM, Özcan M, et al: Adhesion to high-performance polymers applied in dentistry: A systematic review. Dent Mater 2020;36:e93-e108

38. Wang C, Sun F, Zhang J, et al: Effects of surface treatments on the bonding properties of polyetherketoneketone to dentin: An in vitro study. J Prosthet Dent 2021;126:709.e1-709.e10

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39. Abou-Ayash S, Schimmel M, Özcan M, et al. Trueness and marginal fit of implant-supported complete-arch fixed prosthesis frameworks made of high-performance polymers and titanium: An explorative in-vitro study. J Dent. 2021;113:103784

40. Lalama M, Rocha MG, O'Neill E, et al: Polyetheretherketone (PEEK) Post and core restorations: a 3d accuracy analysis between heat-pressed and cad-cam fabrication methods. J Prosthodont. 2021 Nov 10. doi: 10.1111/jopr.13452.

41. Bae SY, Park JY, Jeong ID, et al: Three-dimensional analysis of marginal and internal fit of copings fabricated with polyetherketoneketone (PEKK) and zirconia. J Prosthodont Res 2017;61:106-112

Table 1. Intragroup retentive force differences after each insertion-removal cycle in all tested groups compared to baseline retentive force

	Variation (versus baseline)						
	500	1000	2000	5000	10000	15000	20000
Test 1: Zr-PEKK							
Mean	-1.08	-6.13	-9.75	-10.51	-11.30	-11.61	-11.20
95% CI lower	-4.85	-11.25	-16.66	-19.68	-18.88	-22.32	-21.52
95% CI upper	2.69	-1.00	-2.85	-1.35	-3.72	-0.90	-0.87
p-value	0.562	0.021	0.007	0.026	0.005	0.040	0.035
Test 2: Ti-PEKK							
Mean	5.42	2.02	-2.49	-6.43	-10.24	-13.56	-17.79
95% CI lower	1.66	-3.11	-9.40	-15.59	-17.82	-24.27	-28.12
95% CI upper	9.19	7.14	4.41	2.74	-2.67	-2.85	-7.47
p-value	0.006	0.500	0.467	0.227	0.010	0.026	0.001
Test 3: CoCr-PEKK							

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Mean	3.02	4.07	7.04	11.40	10.24	5.13	0.28
95% CI lower	-0.75	-1.05	0.14	2.24	2.66	-5.58	-10.04
95% CI upper	6.79	9.20	13.95	20.57	17.82	15.84	10.61
p-value	0.196	0.161	0.107	0.058	0.068	0.391	0.956
Test 4: PEKK-PEKK							
Mean	3.34	5.91	8.02	12.40	16.16	17.77	19.21
95% CI lower	-0.43	0.78	1.11	3.24	8.58	7.07	8.89
95% CI upper	7.11	11.03	14.93	21.57	23.74	28.48	29.53
p-value	0.080	0.025	0.024	0.010	0.000	0.002	0.001
Test 5: Au-PEKK							
Mean	2.21	3.14	6.51	11.78	13.73	14.14	14.41
95% CI lower	-1.56	-1.98	-0.40	2.61	6.15	3.43	4.09
95% CI upper	5.97	8.27	13.41	20.94	21.31	24.84	24.73
p-value	0.241	0.257	0.089	0.024	0.001	0.011	0.008
Control: Au-GA							
Mean	4.20	8.58	10.58	17.57	14.25	15.55	10.72
95% CI lower	0.43	3.45	3.67	8.40	6.67	4.84	0.40
95% CI upper	7.97	13.70	17.48	26.73	21.83	26.25	21.04
p-value	0.030	0.002	0.004	0.000	0.001	0.006	0.042

Mean, mean value of the differences with baseline; 95% CI, 95% confidence interval; Zr/PEKK, Zirconia/Polyetherketoneketone; Ti/PEKK, Titanium/PEKK; Cobalt-chrome/PEKK, CoCr/PEKK; Au/PEKK, Gold/PEKK; Au/GA, Gold/Galvano-gold. P value methods = Benjamini & Hochberg.

Figure thumbnails and legends

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Figure 1. All types of primary and secondary crowns. PEEK, Polyetherketoneketone; GA, Galvano-gold; Zr, Zirconia; Ti, Titanium; CoCr, Cobalt-chrome; Au, Gold.

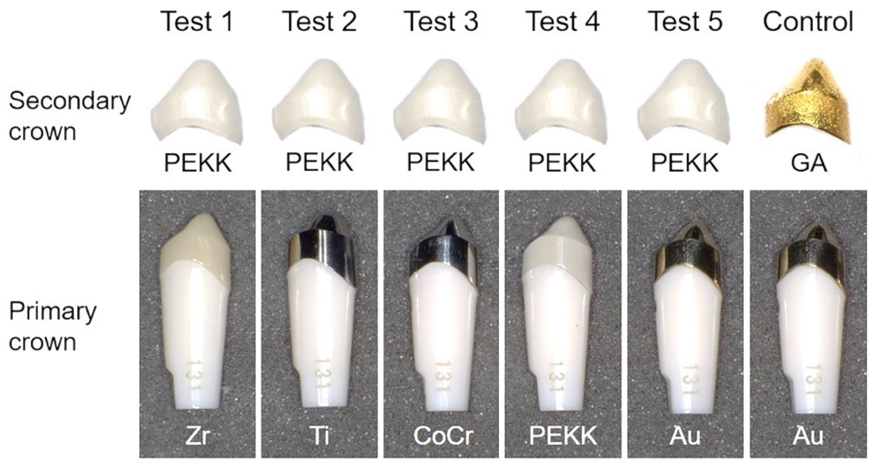

Figure 2. Different views of an acrylic typodont right maxillary canine prepared as a double crown abutment. A, buccal. B, lingual. C, incisal. D, mesial.

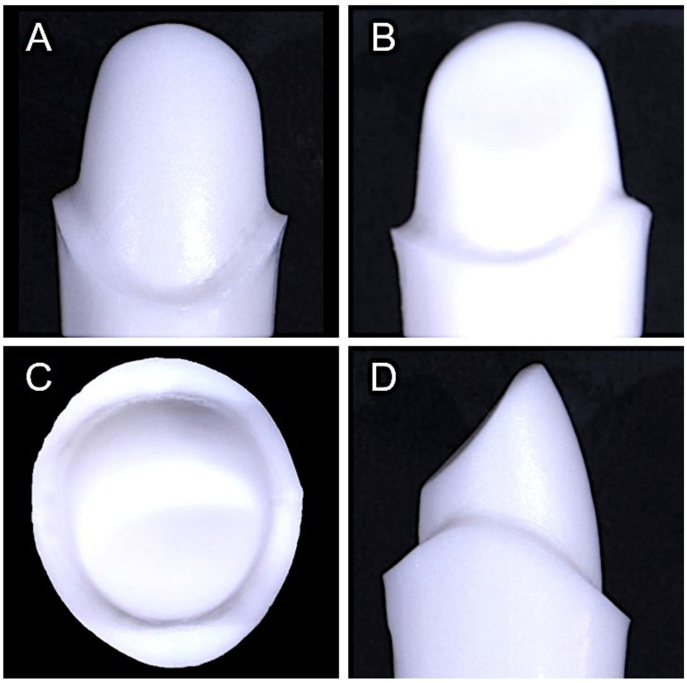

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Figure 3. Representation of a telescopic crown sample. (A) Prosthetic components before attaching a secondary crown to a Cobalt-Chromium (CoCr) cap. (B) Cobalt-chromium (CoCr) cap engaged on a secondary crown. (C) Cross-sectional schematic sample representation.

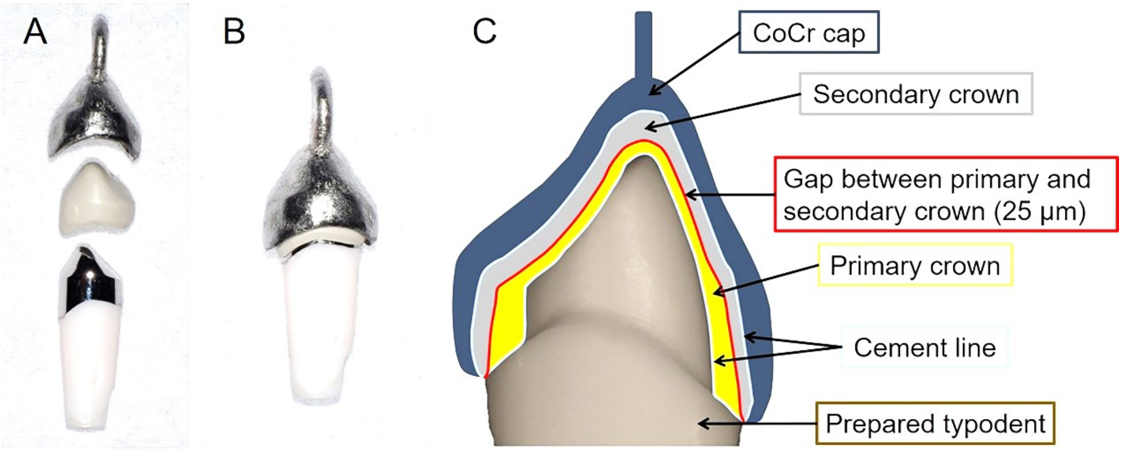

Figure 4. Graphical representation of retentive force of each cycle among groups. Small case letters indicate significant differences within groups. Zr, Zirconia; Ti, Titanium; CoCr, Cobalt-chromium; PEEK, Polyetherketoneketone; Au, Gold; GA, Galvano-gold.

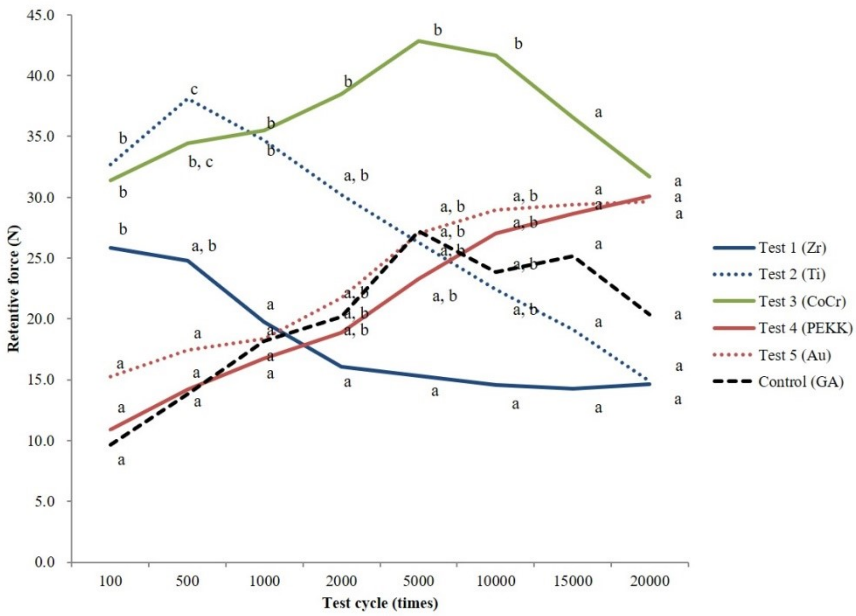

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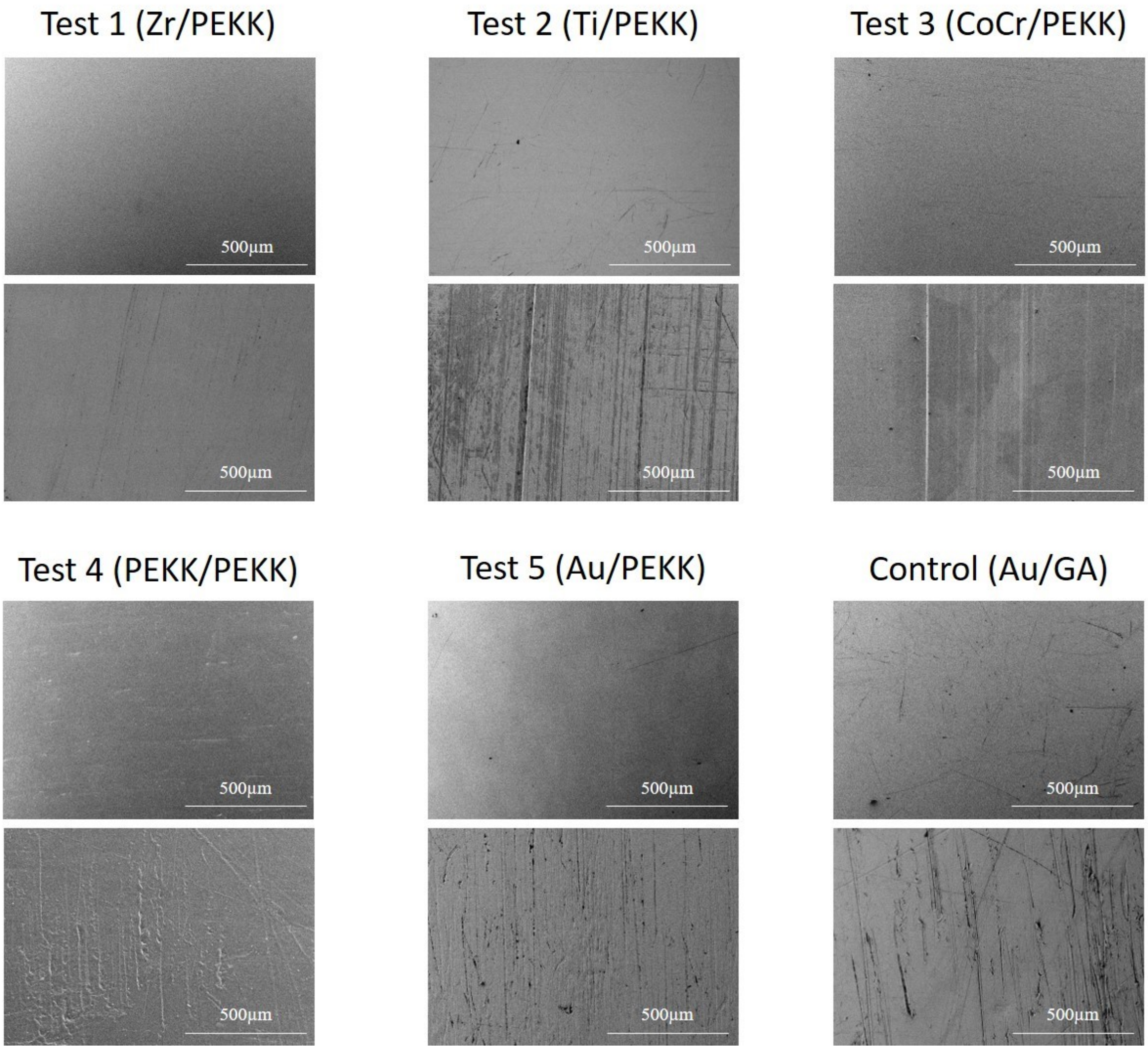
Figure 5. Stereoscopic electron microscope images of primary crown surface before (above) and after (bottom) insertion-removal test (100x magnification). Zr/PEKK, Zirconia/Polyetherketoneketone; Ti/PEKK, Titanium/PEKK; Cobalt-chromium/PEKK, CoCr/PEKK; Au/PEKK, Gold/PEKK; Au/GA, Gold/Galvano-gold.



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