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Research Article

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Compensation of Polyetherketoneketone Secondary Crowns´ Wear in Combination of Primary Crowns made of Different Materials: An *In-vitro* Study

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Abstract

Background: The aim of this study was to investigate the effectiveness of the available methods to compensate the wearing of secondary crowns made from polyetherketoneketone (PEKK).

Methods: Five groups of secondary crowns were investigated. Each group consisted of 10 double crowns. The primary crowns consisted of different dental materials: Gold alloy (group 1), non-precious metal alloy (NPA, group 2), zirconium (group 3), and PEKK (group 4). Group 5 included 10 galvano copings as a reference group. All secondary crowns were made from PEKK. Accordingly, five groups were created: Group 1: Gold/PEKK, Group 2: NPA/PEKK, Group 3: Zirconium/PEKK, Group 4: PEKK/PEKK, and Group 5: PEKK/Galvano/PEKK. Each pair ran through a wear simulator before and after compensation of wearing. The wearing of the samples of the reference group was repaired by galvanisation, for the remaining samples by using Friction-Fit-System (FGP).

Results: After 2,000 cycles, all samples showed constant values before and after wearing compensation. Before wearing compensation, the mean retention forces were: 13.9 N, 19.1 N, 13.3 N, 28.9 N and 4.1 N for gold, NPA, PEKK, zirconium and galvano, respectively. After wearing compensation, the mean retention forces decreased to: 5.1 N, 3.9 N, 3.3 N, and 4.6 N for gold, NPA, PEKK, zirconium, respectively, and increased to 5.5 N for Galvano group.

Conclusions: It can be concluded that post galvanisation still seems to be the proper possible method to compensate the loss of friction of the double crowns.

Introduction

Double crowns have been proven as good retentive elements that are widely indicated for removable partial prostheses. They consist of a primary crown inserted on the tooth or implant and a secondary crown which is integrated into the removable prosthesis.

During insertion and removing of the prosthesis, wearing between the primary and secondary crowns takes place which reduces with time the retention of the prosthesis. This is primarily caused by tribological altering processes of the surfaces of both, primary and secondary crowns. The four main tribological reactions are tribochemical reactions, abrasion, adhesion, and surface disruption; all of them can either occur separately or overlay each other in parts [1,2] Depending on the material, the crowns show different wear patterns.

Double crowns can be constructed from various dental alloys. Those could be gold, non-precious metal alloys (NPA), or zirconium. New material variations like thermoplastic high-performance materials are increasingly gaining interest. Polyaryletherketone (PAEK) is a high-performance thermoplastic polymer material whose properties such as high strength and rigidity within a wide temperature range and excellent biocompatibility make it a valued material throughout the medical field for applications such as artificial joints and spinal implants [3]. In the dental field, polyetheretherketone (PEEK), a member of the PAEK family, is already being used as a framework material in removable dentures and temporary prostheses [4].

Most recently, a new PAEK based polymer, polyetherketoneketone (PEKK) was introduced. The manufacturer reports that PEKK has a similar compressive strength (246 MPa) to that of tooth dentine (297 MPa) and an 80% higher compressive strength than PEEK. Further benefits include low manufacturing costs and lighter weight compared to conventional frameworks in removable prostheses. In addition to its mechanical strength, excellent biocompatibility, shock-absorbing ability, and a wide capability of fabrication processing including milling and pressing make PEKK an attractive dental material for dentures with double crowns [3]. However, the main disadvantage of this material is that it cannot be repaired. Thus, there is no known and well documented possibility to restore lost friction on double crowns made of PEKK. So far, several modifications of metal double crowns are existing to improve friction, such as the TK-Snap-System (company Si-Tec GmbH, D-58257, Germany), friction pins [5] and titanium nitrite coating.

Hence, the aim of this study was to investigate the available method to compensate the wear of the PEKK secondary crowns to have a better retention of the prosthesis without having to manufacture a new prosthesis.

Methods

This study was perfromed on five groups with each 10 primary crowns and 10 secondary crowns. Every primary crown was paired with a secondary crown. Group 1: Primary crowns were made from a gold alloy (NEOCAST® 3, Cendres+Métaux SA, Biel/Bienne, Switzerland), Group 2: Primary crowns were made from a non-precious metal alloy (NPA, Girobond NB, Amann Girrbach, Pforzheim, Germany), Group 3: Primary crowns were made from zirconium (Cercon®base, DeguDent, Hanau-Wolfgang, Germany), Group 4: Primary crowns were made from a high performance polymer polyetherketoneketone (PEKK, Pekkton® ivory, Cendres+Métaux SA, Switzerland), and Group 5: Primary crowns were made from PEKK together with galvano copings (SOLARIS®, Goldbad supra, DeguDent, Germany) were fabricated as a reference group. The secondary crowns were made from PEKK for all five groups. Accordingly, five groups were created: Group 1: Gold/PEKK, Group 2: NPA/ PEKK, Group 3: Zirconium /PEKK, Group 4: PEKK/PEKK, and Group 5: PEKK/Galvano/PEKK (Figure 1).

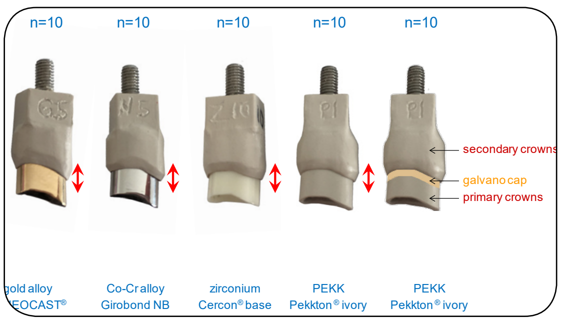

Figure 1: The five groups of double crowns with different dental materials.

A preparation and impression of a premolar was taken to create a model of a prepared tooth for a double crown restoration. The model was cast first in gypsum and then in metal in order to have a single reference model for the fabrication of all 50 primary crowns. For the fabrication of the gold and NPA primary crowns, the casting technique was used for this purpose. The primary crowns made of PEKK and zirconium were fabricated using CAD/CAM technology. The reference model was scanned (3ShapeD810 scanner, Millhouse, Hofheim/Wallau, Germany) and modelled using the 3shape computer software (Millhouse GmbH, Hofheim-Wallau, Germany). The primary crowns were later milled from milling blanks of PEKK and zirconium using the Milling Unit M1 (Zirkonzahn, Gais, Italy). The zirconium primary crowns were sintered following removal from the milling blanks [6].

In the reference group, an additional unit called mesostructure was produced. The mesostructure consists of 10 galvano copings; each of them was fabricated on the 10 primary crowns of the reference group (Group 5). Initially, the inner surfaces of the primary crowns were insulated with release varnish (Pi-Ku-Plast separating varnish, bredent GmbH & Co.KG, Senden, Germany). After the insulation had been air-dried, a mixed composite (Pattern Resin, GC EUROPE N.V., Leuven, Belgium) was filled into the inner surface of the primary crowns. A screw was inserted, which was connected to the primary crown via the composite. The electrode was fixed to this screw with Pattern Resin (GC EUROPE N.V., Leuven, Belgium). The Pattern Resin on the electrode was covered with a light spacer (Light Spacer, YETI DENTAL, Engen, Germany) and then light-cured. This varnish seals the surface and ensures that no foreign body parts from the pattern dissolve in gold liquid. After that, a conductive silver varnish (Preciano® conductive silver varnish, Kulzer GmbH, Hanua, Germany) was applied with a brush to the surface of the primary crowns. It was used to apply an electro-conductive layer for electroforming restorations. For the galvanising process, the slides were equipped with the electrodes and the liquid containers were placed in a galvano bath and perceptibly on top of each other. The liquid (SOLARIS gold solution supra, DeguDent GmbH, Hanua, Germany) was used as a galvano bath. The corresponding parameters for electroplating have been set in the parameter menu. The galvano system offers layer thicknesses of 200 µm, 250 µm, and 300 µm. A gold layer thickness of 300 µm was chosen. The highest layer thickness was selected in order to achieve sufficient stability and thickness of the galvanic caps to protect it from wear and fracture. A gold bath liquid of 95 ml was used for three electrodes. After setting all parameters, the galvanising process was started. Later on, the gold caps were removed from their primary crowns and polished. After manufacturing and cleaning all primary copings and electroformed crowns, primary crowns and galvano copings were scanned using the 3ShapeD810 scanner and matrices modelled using the 3shape software. A Preci-Vertix® (Alphadent NV, Waregem, Belgium) attachment was modelled to allow placement of an allen head socket hex premium steel grub screw M3 x 20 mm.

Milling of the PEKK matrices was performed and grub screws were cemented using AGC® Cem (Wieland Dental+Technik, Pforzheim, Germany). After the secondary crowns were milled, the galvanic crowns were glued into the secondary crowns with AGC® Cem. The secondary crown grub screw was mounted in the wear simulator, the corresponding primary crown was inserted into the secondary crown and then filled with a self-curing resin cast (Palavit® G, Heraeus Kulzer, Wehrheim, Germany). After activation of the electromagnet, the second arm of the wear simulator was brought to slide forward into the resin and the resin left to cure (Figure 2)[6].

The wear simulator used in this study was a prototype specifically designed to perform load changes through inserting and removing matrices and primary crowns axially, with a special periodontium simulating specimen holder for the primary crowns [6,7].

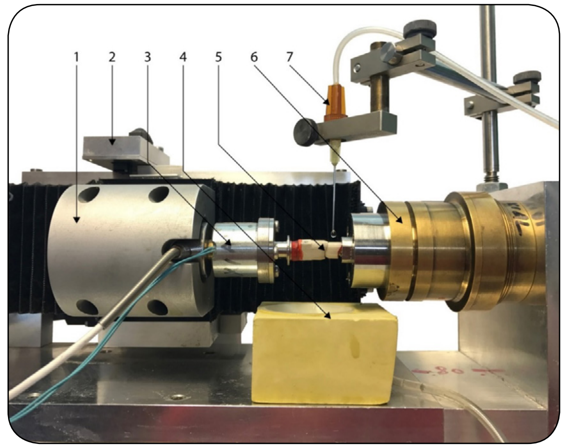

Figure 2: Overview of the measurement setup [6].
1: force transducer to record retention forces.
2: light barrier limiting the orthogonal connecting and disconnecting path.
3: electromagnet.
4: collection container rinsing solution.
5: specimen.
6: periodontium simulating specimen holder.
7: saliva substitute supply.

The control of the wear simulator and recording of the data was performed with DASYLab32 (National Instruments, Munch, Germany). The experimental procedure is described as follows: Secondary crowns and the corresponding primary crowns were mounted in the wear simulator prototype to have 10,000 consecutive cycles of joining and separating (Figure 2). These 10,000 cycles were equivalent to remove and insert the double crown construction three times per day for a wear period of 10 years [7]. To simulate moist intraoral conditions, a saliva substitute (Glandosane®, Cell Pharm, Bad Vilbel, Germany) diluted with distilled water (2:1) was used as a lubricant and applied by a syringe pump (PERFUSOR, secura Co. B. Braun type 871602/1, B. Braun, Melsungen, Germany) at an hourly rate of 2 ml. After 10,000 cycles of insertion and separation, the surface of each primary coping was analysed using a scanning electron microscope (SEM, Phillips® XL 30, Philips, Eindhoven, and The Netherlands) with a magnification of 500 to reveal roughened areas [6].

The wear of groups 1-4 was compensated by a special composite FGP (Friction-Fit-System bredent, Germany). This composite FGP consisted of 22 pieces: 2.50 g friction-composite component A, a 2.5 g friction-composite component B, a 1.25 ml FGP bonding agent, a 3.0 ml FGP isolation, 10 application cannulas (black), 1 mixing pad, 5 disposable brushes, 1 brush holder, and 1 mixing spatula. First, the secondary crowns were hollowed out from the inside with a milling cutter in order to create space for the composite (Figure 3a). Grooves were additionally milled to create a retention surface for the composite.

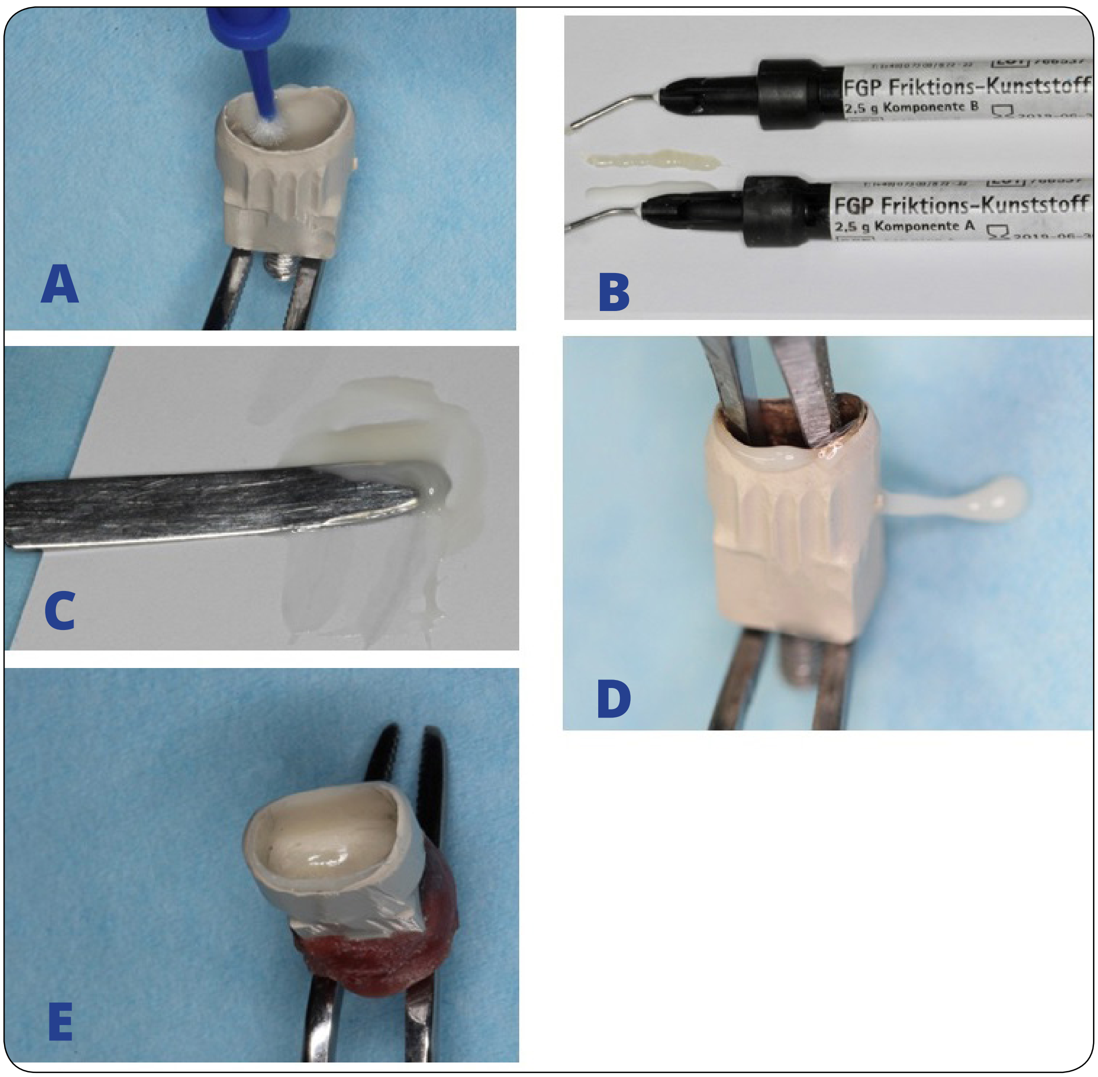

Figure 4: Coating the inner side of the secondary crowns with the repainting resin. a) resin components a and b, b) Mixing of the two components, c) applying of the resin, d) insertion of the primary crown into the secondary crown, and e) the secondary crown after repairing.

A drain hole was then milled into the point around the maximum of the secondary crown. The availability of a space sufficiently homogenous for the composite was checked using xantopren material (Xantopren L blue, Kulzer GmbH, Hanau, Germany, Figure 3b). Xantopren is a low-viscosity c silicone used for precision work. To activate this silicone, it needed a catalyst. After mixing the xantopren with few drops of the catalyst, a mass is formed which is inserted into the secondary crown and the primary crown was then inserted into it. The mixed mass took about one minute to set. After setting, the primary crown was removed from the secondary crown. It was now checked whether a sufficient layer thickness of the xantopren mass is present inside the secondary crown.

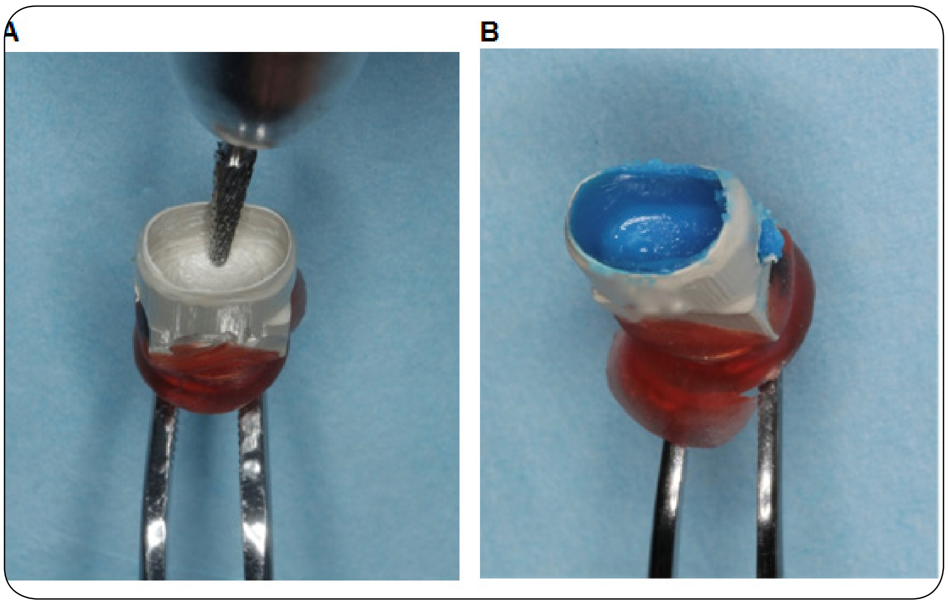

Figure 3: A) Primary crown is hollowed out with a milling drill, and B) Xanthoprene sample to control the layer thickness.

After this thickness checking, the mass was removed. The FGP bonding agent was applied to the inner surfaces of the secondary crowns with a brush and then dry-flushed for 5 minutes (Figure 4a). The outer surfaces of the primary crowns were brushed with a separating varnish (Pi-Ku-Plast separating varnish, bredent GmbH & Co.KG, Senden, Germany) for insulation. After five minutes, the two FGP plastic components A and B were mixed in a ratio of 1:1 and filled bubble-free into the secondary crowns (Figure 4b-c). Under an even pressure, the primary crown was inserted into the secondary crown and the composite remains were removed directly with a dental probe (Figure 4d). After about seven minutes, the secondary crown was removed from the primary crown and a clearly visible FGP composite layer was visible (Figure 4e).

The wear on the Galvano copings from the reference group (Group 5) was compensated by subsequent electroplating. In order to create sufficient contact area for the gold layer, the inner surfaces were thinned out. After the samples were prepared for post-electroplating, the parameters were set. A layer thickness of 5 µm was selected for this purpose. After the galvanisation process, the crowns were cleaned and adapted to the primary crowns. After compensation of wear, the samples were ready for the second run through the wear simulator.

After 10,000 cycles of insertion and separation, the surface of each primary coping was analysed again using a scanning electron microscope (SEM, Phillips® XL 30, Philips, Eindhoven, and The Netherlands) with a magnification of 500 to reveal roughened areas.

Results

All 50 specimens completed 10,000 full cycles of joining and separating before and after wear compensation. The values increased from cycle 0 to 2.000 and achieved constant values after 2.000 cycles.

Before compensation: The mean retention forces at starting time were as follows: 9.0 N, 8.1 N, 4.6 N, 11 N, 6.5 and 5.6 N for gold, NPA, PEKK, zirconium, and galvano, respectively. Mean values for the retention force after 10,000 cycles were 13.9 N, 19.1 N, 13.3 N, 28.9 N and 4.1 N for gold, NPA, PEKK, zirconium, and galvano, respectively (Figure 5). In the SEM analysis, all primary crowns displayed material dependent surface wearing. Primary crowns made of PEKK, NPA, and gold alloy showed similar wearingpattern. The zirconium primary crown showed the least wearing behaviour (Figure 6).

After compensation: The retention forces on starting time were 8.7 N, 5.3 N, 8.0 N, 6.5 N, and 7.0 N for gold, NPA, PEKK, zirconium, and galvano, respectively (Figure 7). The retention force after 10,000 cycles were 5.1 N, 3.9 N, 3.3 N, 4.6 N and 6.4 for gold, NPA, PEKK, zirconium, and galvano, respectively. The SEM analysis after the further 10.000 cycles showed an increase of wearing behaviour on the primary crowns. Zirconium primary crowns had the lowest wearing behaviour (Figure 6).

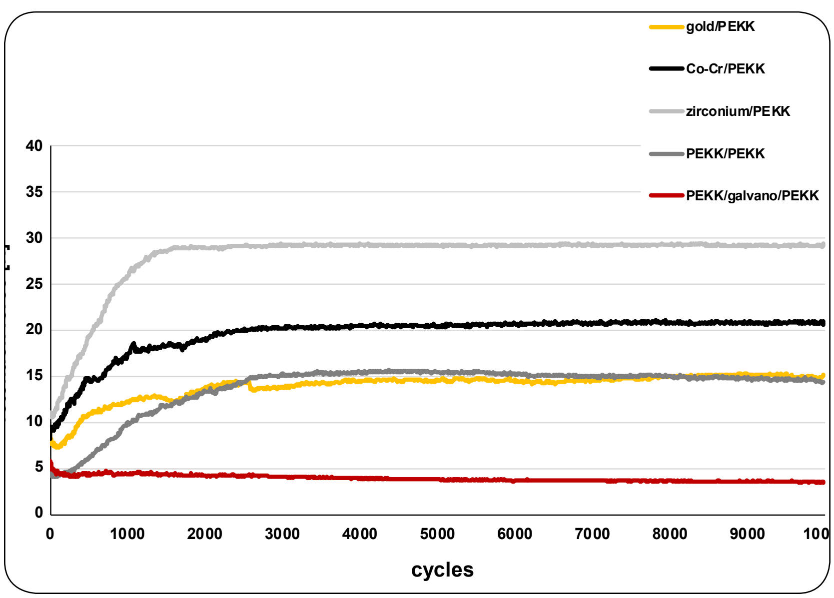

Figure 5: Mean retention forces before compensation of the friction. Microsoft Excel 2018 war sued to create this artwork.

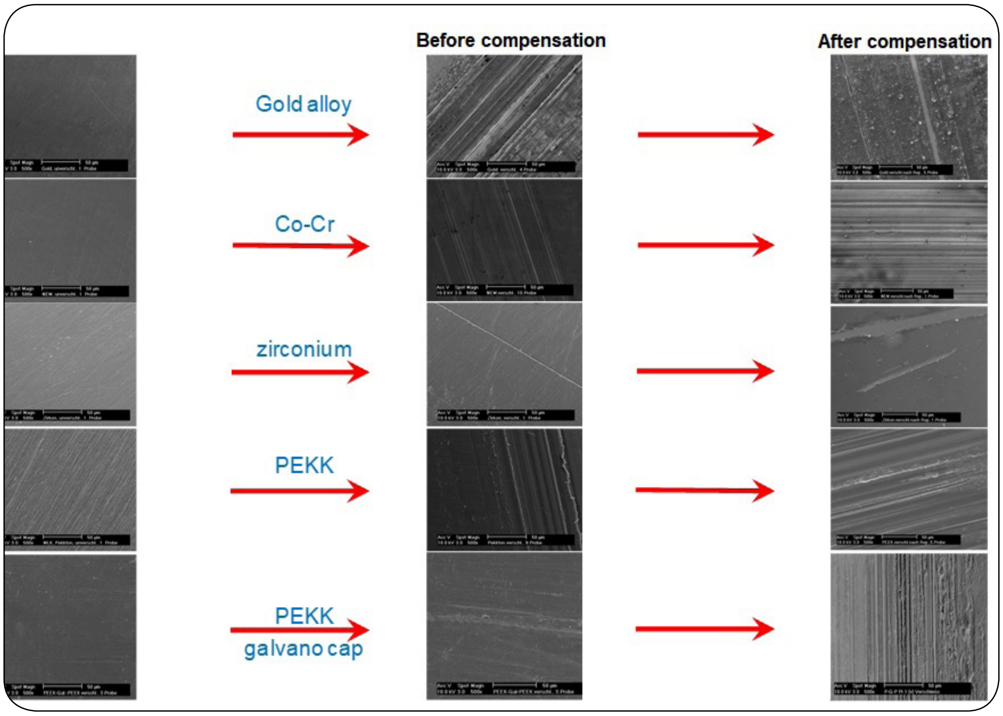

Figure 6: SEM analysis of the surface of the primary crowns before and after compensation of the friction.

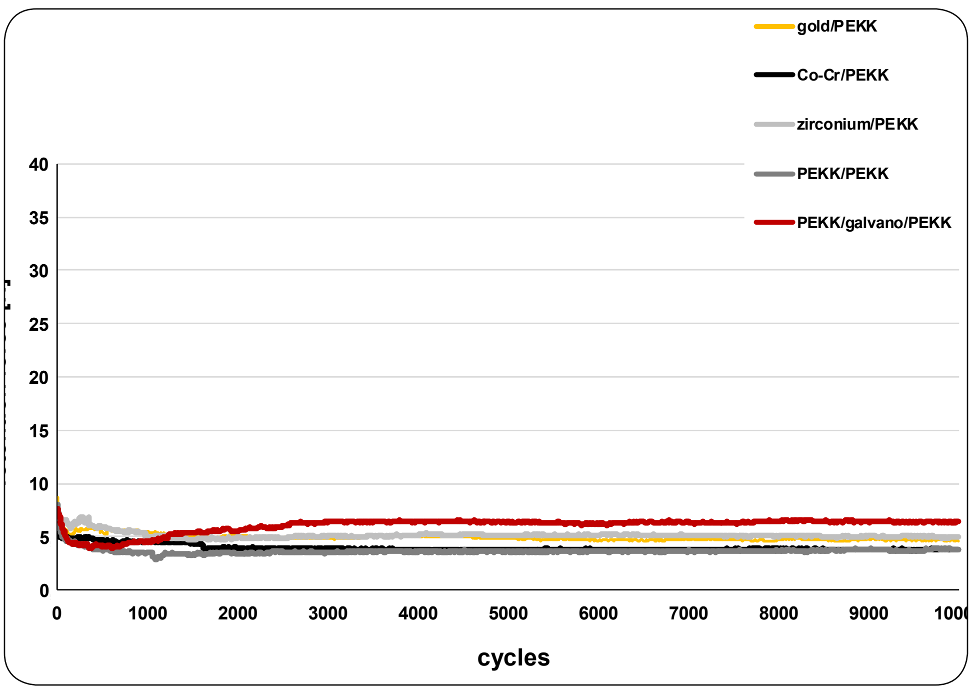

Figure 7: Mean retention forces after compensation of the friction. Microsoft Excel 2018 war sued to create this artwork.

Discussion

In the course of this study, the possibilities of compensating the wear on secondary crowns made of PEKK were examined. Over the using time of prosthesis, the double crowns undergo changes in surface structure due to frictional wear which cause a reduction of the retention force [8]. The wearing behaviour of different dental alloys in combination with PEKK is not well studied according to our knowledge. For this purpose, the wear behaviour of PEKK secondary crowns with primary crowns of different dental materials namely, gold, NPA, zirconium, and PEKK was investigated. Each specimen underwent 10,000 cycles of joining and separating which is equivalent to a clinical wear period of approximately 10 years [7]. Each sample was loaded for 10,000 cycles in the wear simulator and initial results (before wear compensation) showed that the retention forces were depending on the material that had been used.

In all groups, it was noticeable that the retention force increased within the first 2,000 cycles. This period represents the initial time in the life span of the double crowns, including insertion and removal in the dental laboratory during fabrication of the denture and the first weeks of intraoral integration [6]. After 2,000 cycles, the retention forces kept constant. Zirconium produced the highest retention forces (28.9 N), followed by NPA, gold, PEEK, and galvano. The zirconium value was above the range of 3.0-7.0 N that was documented as adequate retention forces per attachment in the literature [9]. However, using a milling procedure with a cone instead of parallel milling would be a possible way to reduce the retention force [6]. The manufacturer reported that zirconium has the ability of extremely high tensile strength of 1,200 MPa. Due to this very high strength, there was minimal wearing of the surface leading to higher retention forces on the double crowns. In comparison to zirconium the 4th group (PEKK/PEKK) showed half the magnitude of the retention forces. The manufacturer reports that PEKK has a tensile strength of 115 MPa, which is noticeably less than that of other dental materials. Group 5, on the other hand, showed very low retention forces compared to the other groups. One reason for this is that electroformed crowns have a very soft surface and are therefore very flexible, which leads to a reduced retention force.

During the second run in the wear simulator (after wear compensation), the test groups 1-4 showed noticeably lower retention forces. Only group 5 showed a slight increase in the retention forces. The reason for this could be that all inner surfaces of the secondary crowns in groups 1-4 had been grinded in with a milling drill in order to create sufficient space for the application of FGP, i.e., a new material was added with different wearing behaviour and the internal fit was changed. Besides this, the galvanically produced double crown works according to a hydraulic principle, whereby the pull-off forces were determined both by the minimum gap between the primary and secondary crowns and by the viscosity of the saliva and the retentive speed of the removable construction. The retention of the galvano double crown is based on cohesion or adhesion of the saliva in the gap area and a negative pressure which builds up when the abutment is removed. The retention forces had been increased after compensation. They have gained values that are necessary to hold prosthesis without damaging the periodontium. After compensation of the wearing using FGP, the SEM analysis showed increased signs of wear on all surfaces of the primary crowns. The reason could be the rough surface of the resin as a replica of the already worn surface of the primary crowns after the first 10,000 cycles of wearing.

Conclusion

Within the limitation of the present study considering the small sample size, it can be concluded that the compensation of the wear on secondary crowns of high-performance polymer (PEKK) in combination with primary crowns of four different dental alloys with FGD resin could be principally carried out. However, by considering the retention forces, there was no improvement of the retention forces thereafter. Moreover, there was an increase of the wearing grooves on the primary crowns. Post galvanisation still seems to be the prober possible method to compensate the loss of friction of the double crowns.

Declarations

Ethics approval and consent to participate

All authors confirm that this work did not involve any use of human subjects or scarifying of animals for the study.

Consent for publication

All authors consent the publication of this study.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

Mimouna Elbajjati: Manufacturing of the double crowns, analysis of the results, Writing-Original draft preparation

Marie Kotthaus: Support the manufacturing of the double crowns

Manfred Grüner: Supervision for the use of the wear simulator

Christoph Bourauel: Reviewing and Editing

Helmut Stark: Reviewing and Editing.

Istabrak Dörsam: Methodology, Reviewing and Editing, Supervision

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