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Retentionsversuche von Doppelkronen: Einfluss von Werkstoff, Konuswinkel und Herstellungstechnik

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1 Einleitung und Zielsetzung

Die Doppelkronentechnik ist in der Zahnmedizin eine bewährte Methode zur Verankerung herausnehmbarer Prothesen. Vorteilhaft sind die ideal Reinigungsmöglichkeit, Parodontienfreiheit und Ästhetik [1]. Vor allem die effiziente Kraftübertragung auf das Restgebiss durch axiale Belastung der Zähne machen Teleskope in der Teilprothetik interessant für Behandler und Patienten[1-4]. Teleskope als Elemente der starren Lagerung bieten eine optimale Retention über Friktion und Konushaftung [1]. Dabei unterscheiden sich Parallelteleskope und Konuskronen durch den Fräswinkel und die dadurch entstehende Haftung. Parallel gefräste Primärkronen mit einem definierten okklusalen Stopp haften durch Friktion, während die Konuskrone einen okklusalen Entlastungsspalt besitzt und Retention durch Verkeilung von Primär- und Sekundärteil bietet.

Metalle und deren Legierungen zählen in der Prothetik zu den am längsten eingesetzten Materialien [5]. Aufgrund ihrer hervorragenden physikalischen und mechanischen Eigenschaften werden Edel- und Nichtedelmetalle bei festsitzendem Zahnersatz und ebenso bei herausnehmbarem Zahnersatz wie der Doppelkronentechnik angewendet. Eine sehr präzise Passung zwischen Sekundär- und Primärkrone kann die Galvanotechnik ermöglichen [6]. Basierend auf einem automatisch ablaufenden, elektrochemischen Abscheidevorgang benötigt das dabei produzierte Goldkäppchen keine Anpassung wie konventionell gegossene Sekundärteile aus Gold [6]. Bei diesen Teleskoppaarungen entsteht die Retentionskraft in erster Linie durch hydrodynamische Effekte und die Adhäsion von Flüssigkeiten [6, 7]. Galvanisierte Sekundärkäppchen bestehen zu 99,9 % aus reinem Gold [7] und haben ein E-Modul von 78,5 GPa [8].

Obwohl Edelmetalle wie Gold als bioverträglich gelten, zeigen einige Studien, dass die Biokompatibilität vor allem in Kombination mit anderen Metallen in der Mundhöhle problematisch sein kann [9-11]. Sowohl der direkte Kontakt von verschiedenen Metallen in der Mundhöhle, als auch im Speichel gelöste Metallionen können zu galvanischer Korrosion führen [10]. Bei der Verwendung verschiedener Metalle in der Mundhöhle, im Englischen als „polymetallism" bezeichnet [11], kann sogar das normalerweise korrosionsbeständige Titan korrodieren [10]. In einer neueren Studie zeigte Titan auch zytotoxische Effekte beim Einsatz als Implantat [12]. Auffallend positiv zeigte sich dort Zirkonoxid (ZrO_2) durch fehlende Zellbeeinflussung [12].

Zirkonoxid, ein vielseitiges, keramisches Material, wird seit langer Zeit in der Medizin verwendet [13]. Zusätzlich zum Einsatz in der orthopädischen Chirurgie gibt es auch in der Zahnmedizin ein weites Feld von Anwendungsmöglichkeiten. Es wird für Kronen [14] und Brücken [15], Implantatabutments [16] und herausnehmbare Prothesen [17] verwendet. Ursächlich dafür sind seine hervorragenden Eigenschaften wie Biokompatibilität [12, 13], mechanische Festigkeit [13], Ästhetik und chemische Widerstandsfähigkeit [18-20]. Die physikalischen Eigenschaften von Zirkonoxid können durch die Stabilisierung mit dem Metalloxid Yttrium (Y_2O_3) [13] verstärkt werden. Das resultierende Yttrium-stabilisierte tetragonale Zirkonoxid (Y-TZP) wurde bereits vielfach eingesetzt und als Material für Teleskopkronensysteme [17, 18] untersucht.

Ein weiteres, wie ZrO_2 sehr biokompatibles Material ist Polyetheretherketon (PEEK). Es wird bereits in verschiedensten Bereichen angewendet, z.B. als Zahnimplantate [21], provisorische Abutments [22], Kronen und Brücken [23, 24], Implantat getragene Stege und Klammern für herausnehmbare Prothesen [25, 26]. PEEK, ein modifiziertes Polyetherarylketon (PEAK), ist ein thermoplastisches Hochleistungspolymer mit einem Schmelzpunkt von 343°C. Die geprüften physikalischen Eigenschaften [27], Abrasionsbeständigkeit [28], hohe Festigkeit [27], und geringe Wasserabsorption und -löslichkeit [29] machen dieses Material interessant für die Zahnmedizin. Im Dentalbereich gibt es bisher drei Verarbeitungswege für PEEK: erstens das Fräsen aus Ronden mit CAD/CAM-Software, zweitens das Pressen aus Granulatmaterial oder drittens das Pressen aus zu Pellets geformtem Material mit einer speziellen Vakuum-pressmaschine. Dabei sind die Ronden und Pellets vorgepresste Formen aus dem Rohmaterial PEEK Granulat. Um das Anwendungsgebiet für die Zahnmedizin noch auszuweiten ist es zudem nötig, PEEK mit weiteren Kunststoffmaterialien wie zum Beispiel Verblendkunststoffe verbinden zu können. Obwohl PEEK gegen Oberflächenmodifikation beständig ist, kann durch die Verwendung von MMA-enthaltende Haftvermittler nach Ätzung ein geeigneter Klebeverbund erreicht werden [30].

Ebenfalls für Primärkronen kann die Kobalt-Chrom-Legierung (CoCr), ein wesentlich steiferes Material mit einem E-Modul ähnlich dem von Y-TZP, verwendet werden. CoCr wird aufgrund der Erfahrung in der Vergangenheit oft als Vergleichsmaterial in Studien verwendet und zeigt prothetische Langzeitstabilität [31]. In Kombination mit Galvanokäppchen wurde es bereits in einer Studie [31] untersucht die zeigte, dass CoCr tatsächlich höhere Retentionskraft-Werte als Gold oder ZrO_2 hat.

In der vorliegenden Dissertation werden Doppelkronenkombinationen aus den vier verschiedenen Dentalmaterialien (Y-TZP, PEEK, CoCr, Gold) hinsichtlich ihrer Retentionskräfte verglichen. Außerdem wurde untersucht welcher Einfluss auf die Retentionskräfte durch den Verarbeitungsweg von PEEK ausgeübt wird. Dafür wurden drei verschiedene Gruppen von PEEK-Prüfkörper hergestellt. Wie bereits erwähnt einerseits mittels CAD/CAM Software aus Ronden gefräst und andererseits gepresst aus Granulat oder Pellets. Weiterhin wurde der Einfluss der Teleskopwinkel (0°, 1° und 2°) auf die Retentionskräfte untersucht. Hierbei dienten als Vergleich Gruppen mit Primärteilen aus CoCr und Gruppen mit galvanisierten Sekundärteilen.

Der erste Teil dieser Arbeit beschäftigt sich mit der Frage nach der Bedeutung des Primärkronenmaterials. Hierzu werden die Retentionskräfte von Primärkronen aus Y-TZP oder CoCr jeweils mit Sekundärkronen aus Y-TZP oder Galvanokäppchen verglichen. Der zweite Teil der Arbeit prüft die Eignung von PEEK-Sekundärkronen auf Y-TZP Primärkronen, dabei wird besonders die Abhängigkeit der drei verschiedenen Verarbeitungswege von PEEK auf die Retentionskraft betrachtet.

2 Eigene Arbeiten

Im Folgenden werden zwei Originalarbeiten vorgestellt und diskutiert.

2.1 Originalarbeit: Merk S, Wagner C, Stock V, Schmidlin PR, Roos M, Eichberger M, Stawarczyk B. Retention load values of telescopic crowns made of Y-TZP and CoCr with Y-TZP secondary Crowns: Impact of different taper angles. Materials 2016; 9: 354

Zusammenfassung

Ziel: Verschiedene Doppelkronen-Kombinationen aus Y-TZP- und Kobalt-Chrom Primärkronen mit Y-TZP-Sekundärkronen und Galvanokäppchen werden bezüglich ihrer Retentionskräfte verglichen.

Material und Methode: 30 Y-TZP Primärkronen mit Galvanokäppchen (Z/G) und Y-TZP Sekundärkronen (Z/Z) und 30 Kobalt-Chrom Primärkronen mit Galvanokäppchen (C/G) und Y-TZP Sekundärkronen (C/Z) wurden jeweils mit drei verschiedenen Konuswinkeln (0°, 1° und 2°) hergestellt. Abgesehen von den Galvanokäppchen wurden alle Prüfkörper maschinell mittels eines CAD/CAM Systems gefräst, später gesintert und manuell nachbearbeitet. Um die Galvanokäppchen zu stabilisieren wurden sie in eine Tertiärstruktur geklebt. Die Sekundärkronen wurden mit einer Öse konstruiert, die die Selbstausrichtung mit der Aufhängung an der Prüfmaschine gewährleistet. Pro Prüfkörper wurden 20 Abzugsversuche in einer Universalprüfmaschine durchgeführt. Jeder Zyklus beinhaltete das Benetzen der Doppelkronen mit künstlichem Speichel und deren Beschweren für 20 Sekunden mit einem 5 kg schweren Gewicht. Die Daten wurden mittels einfacher und zweifacher ANOVA analysiert.

Ergebnisse: Die Doppelkronen-Kombination C/Z zeigte bei einem Winkel von 1° höhere ($p=0.009$) Retentionskräfte, als bei 0° und 2°. Ebenso zeigte die Kombination C/G bei 1° höhere ($p=0.001$) Retentionskräfte als bei 0° und 2°. Innerhalb der 0°-Gruppe zeigten Galvano Sekundärteile geringere Retentionskräfte als Y-TZP Sekundärteile ($p<0.001$). Das Material der Primärteile zeigte keinen Einfluss der Retentionskräfte innerhalb der 0°-Gruppe. Die Kombination Z/G zeigte geringere Retentionskräfte im Vergleich zu C/Z innerhalb der 1°-Gruppe ($p=0.007$) und Z/Z in der 2° Gruppe ($p=0.006$).

Schlussfolgerung: Hinsichtlich der verschiedenen Winkel können nur bei der 1°- Gruppe in zwei von vier Gruppen (C/Z und C/G) signifikante Unterschiede festgestellt werden. Es zeigte sich, dass das Material der Primärteile keinen Einfluss auf die Retentionskräfte hatte. Galvanokäppchen zeigten im Vergleich zu Y-TZP Sekundärteilen geringere Retentionskräfte.

materials

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Article

Retention Load Values of Telescopic Crowns Made of Y-TZP and CoCr with Y-TZP Secondary Crowns: Impact of Different Taper Angles

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Abstract: This study aimed to examine and compare the retention load values (RL) of different telescopic crown assemblies (Y-TZP and CoCr primary crowns with electroformed and Y-TZP secondary crowns each) with three different taper angles (0˝, 1˝ and 2˝). Thirty Y-TZP primary crowns with electroformed gold copings (Z/G group) and Y-TZP secondary crowns (Z/Z group) and 30 CoCr primary crowns with electroformed gold copings (C/G group) and Y-TZP secondary crowns (C/Z group), each with taper angles of 0˝, 1˝ and 2˝, were fabricated, respectively. With the exception of the electroformed gold copings, all specimens were Computer-Aided-Design/Computer-Aided-Manufacturing (CAD/CAM)-milled, then sintered and afterwards manually adapted. In order to stabilize the gold copings, they were fixed in a tertiary structure. The secondary crowns were constructed with a hook, which ensured self-alignment with an upper chain. Afterwards, 20 pull-off test cycles were performed in a universal testing machine under artificial saliva and after weighing the secondary crowns with a 5 kg object for 20 s. Data were analyzed by one-way and two-way Analysis of Variance (ANOVA). C/Z with 1˝ showed higher ($p = 0.009$) RL than 0˝ and 2˝ tapers. C/G at 1˝ also showed higher ($p = 0.001$) RL than at tapers of 0˝ and 2˝. Z/G and C/G at 0˝ showed lower RL than Z/Z and C/Z ($p < 0.001$). Primary crowns had no impact on the 0˝ group. Z/G showed lower RL as compared to C/Z within the 1˝ group ($p = 0.007$) and Z/Z in the 2˝ group ($p = 0.006$). The primary crown material had no influence on RL. Electroformed copings showed lower RL. Further investigations for 1˝ as well as for the long-term performance after thermomechanical aging are necessary.

Keywords: Y-TZP; telescopic crowns; CAD/CAM; retention load; electroforming

1. Introduction

Zirconia (ZrO_2), a ceramic material with great potential, has been used in different medical applications for quite some time [1]. Especially in orthopedic surgery, ceramic materials have proven themselves for a long time [1,2]; the reason they are being used is based on their excellent mechanical properties: temperature stability, strength and resistance to acids and alkalis [3]. In addition, dental medicine has recognized a wide range of other applications of the material in the field: It is used for crowns [4], fixed dental prostheses (FDPs) [5], implant abutments [6], removable partial dentures

(RDPs) [7], *etc*. Consequently, ZrO_2 has become a widely used material in dentistry [4,6,8–11] because of its excellent properties such as biocompatibility [1,2], mechanical strength, aesthetic appearance and chemical resistance [9–11], and the material has also proven outstanding biocompatibility in clinical studies [1,2]. Furthermore, it can be polished or ceramically veneered [10,11], which is also very important in the field of esthetic dentistry. The physical properties of the ZrO_2 material can be improved by stabilization with the metallic oxide yttrium (Y_2O_3) [1]. The resulting yttrium-stabilized tetragonal zirconium oxide (Y-TZP) shows even better mechanical properties than other zirconia oxides [2], which is a result of the crystalline modification from a tetragonal (T) to monoclinic (M) arrangement [2]. This T-M transition occurs after a cracking which creates energy to seal the crack by expansion [2].

Regardless of the stabilizing procedure, Y-TZP proved itself in long-term studies. Two recent clinical studies on single crowns yielded good success rates [4,8]. Three-unit FDPs also presented a survival rate similar to conventional FDPs [5] after 10 years. In a seven-year study, Kolgeci and co-workers observed that Y-TZP-based prostheses are clinically successful on dental implants as well [12]. This was corroborated by another 10-year clinical study [13].

Y-TZP was also used and studied as a material for telescopic crown systems [7,9]. Most of these studies assessed assemblies with Y-TZP primary crowns and secondary crowns of a different material, especially gold alloy. In this context, the combination of a ZrO_2 primary crown with a galvanic-formed gold coping showed more a predictable and less excursive retention load than conventionally cast telescopic crowns [9,14]. However, primary and secondary crown assemblies totally made of Y-TZP have not been thoroughly investigated so far. To the authors' best knowledge there is only one investigation of such homogenous Y-TZP joints [7].

The electroforming process can achieve a very precise fit for the primary crown onto the secondary crown [15], which is a result of the manufacturing process. A thin layer of silver conductive lacquer applied on the outer surface of the primary crown and the automatically running electroplating process create the precise secondary coping [15]. The gold coping produced demands no adjustment like conventionally cast ones do [15]. For these telescopic joints, hydrodynamic effects especially and the adhesion of liquids provide the retention load [15,16]. The galvanic copings are made of 99.9% pure gold [16] with an elastic modulus of 78.5 GPa [17]. Another much stiffer metal with an elastic modulus similar to that of Y-TZP can be used for primary crowns, namely cobalt-chromium alloy (CoCr). According to the manufacturer's specifications, the value is 204 GPa for Y-TZP and 200 GPa or greater for CoCr. The latter one, assembled with the electroformed secondary crown, was investigated by Engels and co-workers [14]. This study showed that CoCr had actually higher retention load values as compared to gold or ZrO_2 crowns.

Even if Besimo *et al.* observed no significant influence of the primary crown material [18], there has been a contrary outcome documented. In this investigation the surface roughness of the primary crowns affected the retention load of electroformed assemblies [19]. In recent studies it was assumed that different hardness levels [9] and the surface treatments such as polishing [16] may have an impact on the retention load values.

The aim of the present study was to determine the retention load values of differently assembled telescopic crown systems:

1. Y-TZP primary crown with a secondary crown made of Y-TZP (Z/Z) and electroformed copings (Z/G);
2. CoCr primary crown with a secondary crown made of Y-TZP (C/Z) and electroformed copings (C/G).

Each assembly was created with three different taper angles (0˝/1˝/2˝).

The first null hypothesis was that the taper angle will show no influence on the retention loads. The second null hypothesis was that the material of the primary crown has no impact on the retention load.

2. Materials and Methods

This study determined the maximum retention load values of 120 telescopic crowns (Figure 1). The primary crowns were made from:

1. Yttrium-stabilized tetragonal zirconium dioxide polycrystals (Y-TZP) (Ceramill ZI 71; AmannGirrbach AG, Koblach, Austria, LOT: 1303002) or;
2. Cobalt-chromium alloy (CoCr) (Ceramill Sintron 71 16 millimeter; AmannGirrbach AG, LOT: 1303045).

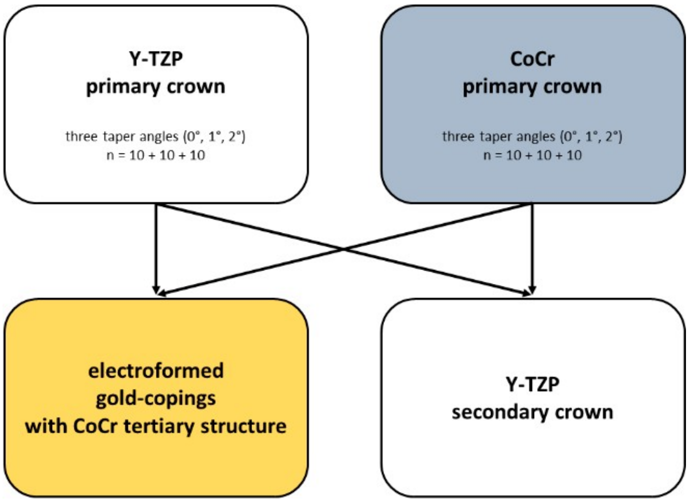

Figure 1. Treatment groups and combination of the telescopic crown assemblies.

The secondary crowns were made from Y-TZP (CERAPP Zirkon Blank; Ingenieurbüro Sax IBS, Kaisersesch, Germany, LOT: 3YZ-L34-1106313-W-007-18-009) and electroformed gold copings fixed in a CoCr tertiary structure (Ceramill Sintron; AmannGirrbach AG, LOT: 1402005).

2.1. Retention Load Measurement

Each combination of primary and secondary crowns was tested in 20 cycles by a pull-off test under the same conditions, *i.e.*, moistening of the primary crown with artificial saliva (Glandosane, No. 9235461109, cell pharm, Bad Vilbel, Germany) and weighing the secondary crown with a weight of 5 kg for 20 s. For measuring the retention load, specimens were placed and fixed in a universal testing device (Zwick 1445, Zwick, Ulm, Germany). For this purpose, the secondary crowns were provided with a retaining jig that was connected to a hook. The latter and its upper chain were part of the pull-off test set-up and ensured self-aligning. The tests were performed with a cross head speed of 50 mm/min.

2.2. Fabrication of Primary Crowns

As a basis for the abutments a prepared plastic model tooth was duplicated with a silicone mold (Adisil blau 9:1, Siladent, Goslar, Germany). Sixty wax abutments (Milling- & Universal Wax blue; GEBDI, Engen, Germany) were transferred into a base metal alloy (Remanium GM800+; Dentaurum, Ispringen, Germany, LOT: 936) using the conventional casting method. Afterwards, these metals abutments were scanned (Ceramill map 300, AmannGirrbach AG) and six different constructions of primary crowns were designed: three for zirconia primary crowns and three for cobalt-chromium primary crowns with three tapers each, a 0˝ with chamfer preparation and a 1˝ and 2˝ with tangential ending, respectively (Ceramill mind, AmannGirrbach AG). Each design was CAD/CAM milled 10 times with a milling machine (Ceramill Motion 2 System, AmannGirrbach AG) from chalky Y-TZP (Ceramill ZI 71, AmannGirrbach AG, LOT: 1303002) and cobalt-chromium-molybdenum alloy blanks (Ceramill Sintron 71 16 millimeter; AmannGirrbach AG, LOT: 1303045). In summary, 30 Y-TZP primary crowns and 30 CoCr primary crowns (Figure 2b) were sintered.

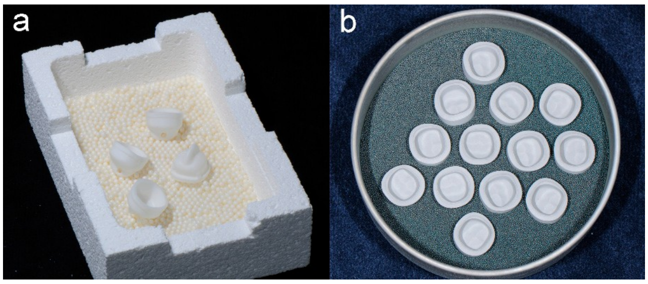

Figure 2. Comparison of the sintering procedures: Sinter support structure with Y-TZP secondary crowns (**a**); and CoCr primary crowns (**b**).

2.2.1. Y-TZP Primary Crowns

The sintering process was performed in a sintering furnace according to the manufacturer's recommendations (Ceramill therm, AmannGirrbach AG). After adhesive placement using a self-adhesive resin cement (RelyX Unicem 2, 3M ESPE, Seefeld, Germany, LOT: 509981), the sintered Y-TZP crowns were mounted in a socket in their insertion direction. Afterwards, the tapers were manually adapted with a water-cooled turbine (W & H Perfecta 900, W & H Dentalwerk Bürmoos GmbH, Bürmoos, Austria) and fixed in a parallelometer (F4 basic, DeguDent, Hanau, Germany). For this purpose, diamond burs (Ceramic Art Set 4371/4369, ZR374M/F, Komet Dental GmbH & Co. KG, Lemgo, Germany) with three corresponding grit sizes (151 µm/107 µm/46 µm) for 0˝, 1˝ and 2˝ tapers were used as recommended in the literature. For polishing, a three-step silicone polishing system (Ceramic Art Set 4371, Komet Dental GmbH & Co. KG) was applied with round brushes and polishing paste (Komet Dental GmbH & Co. KG, REF: 9638900190; YETI DIA-GLACE; YETI Dentalprodukte GmbH, Engen, Germany, Pat. 3832085.1).

2.2.2. CoCr Primary Crowns

According to the manufacturer's recommendation, the chalky cobalt-chromium crowns were sintered in a protective atmosphere with argon gas (Ceramill Argotherm, AmannGirrbach AG). After being air-abraided with 110 µm mean alumina particles with 2 bar (basic Quattro IS; Renfert GmbH, Korox 110, Bego GmbH & Co. KG, LOT: 14878430513), the primary crowns were cemented and mounted in a socket similar to the Y-TZP procedure as mentioned above. They were adapted with a hand piece fixed in a parallelometer and cross-cut burs with appropriate tapers (tungsten carbide burs, Komet Dental GmbH & Co. KG, LOT: 042830) and finished with polishing brushes and paste (Komet Dental GmbH & Co. KG, LOT: 226983; Abraso-Starglanz asg, bredent GmbH Co. KG, Senden, Germany, REF: 52000163).

2.3. Fabrication of Secondary Crowns

2.3.1. Y-TZP Secondary Crowns

The 60 polished primary crowns (30 ˆ Y-TZP + 30 ˆ CoCr) were scanned (Arti-Spray, white, BK 285, Dr. Jean Bausch GmbH & Co. KG, Cologne, Germany; Ceramill map 300, AmannGirrbach AG) and respective constructions were designed (N = 10 per taper), *i.e.*, 30 constructions on Y-TZP primary crowns and 30 on cobalt-chromium primary crowns, respectively. Afterwards, these 60 Y-TZP secondary crowns were milled from chalky Y-TZP blanks (CERAPP Zirkon Blank; ZENO Tec System, ZENO 4030 M1, Wieland Dental GmbH & Co. KG, Pforzheim, Germany). After the sintering process

(Figure 2a), the fitting of the secondary crowns to their primary crowns was adapted with diamond burs (ZR 8850, Komet Dental GmbH & Co. KG) and the polishing process was handled similarly to the Y-TZP primary crowns.

2.3.2. Electroformed Secondary Crowns

The other 60 secondary crowns worked with a galvanic formed inner coping, produced in a galvanic device (Hafner HF 600.3; C. Hafner GmbH & Co. KG, Pforzheim, Germany) in an electroforming gold bath containing electrolyte solution (Helioform H Electrolyte; C. Hafner GmbH & Co. KG, LOT: 00433724) and the related gold solution (Helioform H Concentrate, C. Hafner GmbH & Co. KG, LOT: 0043468). The finished copings were mounted (AGC Cem Automix system, Wieland Dental GmbH & Co. KG, LOT: 697720) into a superstructure to enhance the thin gold copings and to carry out the pull-off tests.

The electroforming process lasted 14 h, applying 17 mA voltage per crown. For this process, the inner surface of the finished detached primary crowns (30 ˆ Y-TZP + 30 ˆ CoCr) was air-abraded and cleaned. Then, the two components of polyurethane resin (PU; Helioform Polyurethane material compound A & B; C. Hafner GmbH & Co. KG, LOT: 512) were mixed and agitated in a 1:1 ratio for 30 s, filled into the primary crowns and hardened for 30 min. These PU-auxiliary parts were combined with copper stickers resulting in the anode. For accumulation of gold ions the silver conductive lacquer presented the guide rail. Using the air-brush gun allowed an even, thin coating of silver conductive lacquer (Helioform silver conductive spacer for airbrush; C. Hafner GmbH & Co. KG, LOT: 02/13) on the surface area of the primary crowns (Figure 3). A wider track of silver conductive lacquer (Helioform silver conductive spacer; C. Hafner GmbH & Co. KG, LOT: 02/13) was necessary to connect the surface area with the copper anode. The bottom and the fringe area were covered with a light-curing cover lacquer (Helioform cover varnish LC; C. Hafner GmbH & Co. KG, LOT: 122574) to prevent electroforming at these areas.

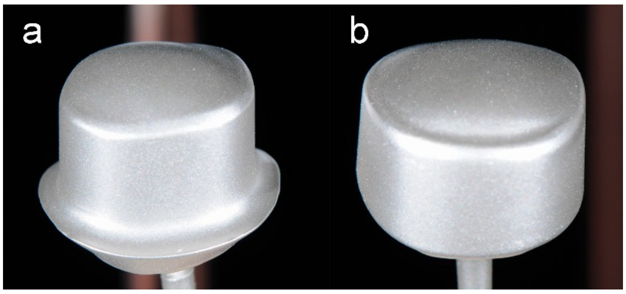

Figure 3. Primary crowns of (**a**) 0˝; and (**b**) 2˝ on copper sticks, air brushed with silver conductive lacquer.

To prevent a plastic deformation, the delicate gold copings were pasted into a CoCr tertiary structure (AGC Cem Automix system, Wieland Dental GmbH & Co. KG, LOT: 697720) (Figure 4).

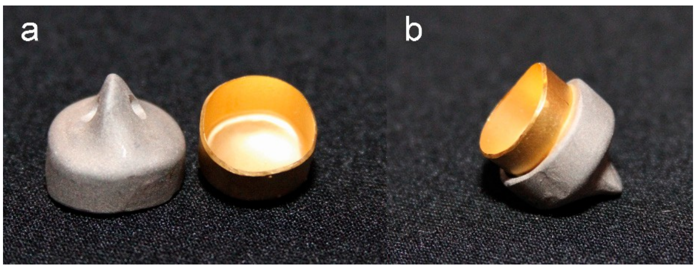

Figure 4. Electroformed gold coping and CoCr tertiary structure, separate (**a**); and assembled (**b**).

2.4. Statistical Analyses

The maximum retention load values of each assembly were used for descriptive statistics, including mean, standard deviation (SD), 95% confidence interval (CI), minimum, median and maximum values. Furthermore, verification of data normality distribution was executed by Kolmogorov-Smirnov and Shapiro-Wilk tests. Significant differences in maximum retention load between the groups were detected by one-way and two-way ANOVA, ensured by the *post-hoc* Scheffé test. IBM SPSS (Version 22; IBM Corporation) was basic for the statistical tests with $p < 0.05$ as the significant level.

3. Results

With regard to the taper, Y-TZP secondary crowns with 1˝ on CoCr primary crowns showed significantly higher ($p = 0.009$) retention load values compared to those of 0˝ and 2˝. Electroformed copings on CoCr with 1˝ also showed significantly higher ($p = 0.001$) retention load values than with 0˝ and 2˝. In addition, secondary crowns on Y-TZP primary crowns showed no significant differences in retention load regarding the taper (Z/Z: $p = 0.167$; Z/G: $p = 0.069$) (Table 1).

Table 1. Descriptive statistics such as mean with standard deviation (SD), 95% confidence intervals (95% CI) and the non-parametric statistics (minimum/median/maximum). All values are presented in Newton (N).

Taper Angle	Assemblies	Mean ˘ SD	95% CI	Min/Median/Max
0˝	C/Z	17.38 ˘ 6.98	(12.2;22.4)	7.6/14.9/29.6
	Z/Z	17.63 ˘ 5.16	(13.8;21.4)	6.4/18.0/24.0
	C/G	10.38 ˘ 2.85	(8.2;12.5)	4.8/10.1/14.0
	Z/G	7.73 ˘ 5.37	(3.7;11.6)	1.1/7.7/15.0
1˝	C/Z	26.44 ˘ 5.48	(22.4;30,4)	15.9/27.4/34.1
	Z/Z	17.92 ˘ 6.92	(12.8;22.9)	8.4/16.5/30.0
	C/G	22.40 ˘ 8.73	(16.0;28.7)	12.5/20.3/37.0
	Z/G	14.63 ˘ 8.26	(8.6;20.6)	3.1/12.1/29.0
2˝	C/Z	16.86 ˘ 8.59	(10.6;23.1)	5.1/18.3/31.4
	Z/Z	22.71 ˘ 7.31	(17.3;28.0)	16.4/18.4/35.4
	C/G	14.74 ˘ 6.05	(10.3;19.1)	4.2/14.3/25.9
	Z/G	11.35 ˘ 4.87	(7.7;14.9)	5.3/10.2/20.5

C/Z: CoCr primary crown, Y-TZP secondary crown; Z/Z: Y-TZP primary crown, Y-TZP secondary crown; C/G: CoCr primary crown, electroformed gold coping; Z/G: Y-TZP primary crown, electroformed gold coping.

Concerning the fabrication method and disregarding the primary crowns, electroformed secondary crowns with 0˝ showed significantly lower retention load values than secondary crowns made of Y-TZP ($p < 0.001$). Other than that, the primary crowns have no significant impact on the retention load within the 0˝ taper group. Z/G showed significantly lower retention load values compared to the C/Z within the 1˝ taper group ($p = 0.007$) and Z/Z in the 2˝ taper group ($p = 0.006$).

4. Discussion

This study examined the retention loads of different telescopic crown systems of three different tapers, *i.e.*, 0˝ with a chamfer and 1˝ and 2˝ with a tangential ending, respectively. Two different materials were used as primary crowns: Y-TZP and CoCr. Both were CAD/CAM-milled and later on sintered and they displayed comparable elastic moduli. Each primary crown was coupled with a Y-TZP secondary crown and an electroformed coping.

The first null hypothesis regarding the taper angle was rejected since the two telescopic crown systems C/Z and C/G with 1˝ showed significantly higher retention load values as compared to those with 0˝ and 2˝. Basically, the design of the primary crown could have an influence on the retention load values as shown in an earlier study [19]. According to Beuer and co-workers, 0˝ telescopic crowns need a chamfer design to create adhesion, but this has been shown to negatively influence the retention forces [19].

Our result seems to be in contrast to the matter of common knowledge based on Ohkawa *et al.* and other studies [9,20,21], who have shown that an increasing retention load occurs with decreasing taper angles. This statement is based on investigating taper angles from 0˝ to 6˝. Turp *et al.* [9] emphasized that a statistically significant difference occurred only with a difference of more than 2˝ in taper angle. This result was corroborated by our findings, namely by the groups Z/Z and Z/G, which showed no significant differences in retention load within the three taper angle groups of 0˝, 1˝ and 2˝. However, Güngör recommended that the taper angles should not exceed more than 2˝ in case of long-term use [20]. Higher retention load values for 1˝ have been confirmed in the literature recently [22]. The authors examined the range from 0˝ to 2˝ and also observed higher retention load values for 1˝ telescopic crowns.

In addition, the second null hypothesis was accepted because no significant differences could be found between groups with different primary crowns and the same secondary crown types (C/Z and Z/Z; C/G and Z/G). In the present study the two primary crown materials had similar elastic moduli (204 GPa for Y-TZP and 200 GPa or greater for CoCr). Already in 1975, Garvie characterized a non-precious metal alloy and ceramic with his description of ZrO_2 as "ceramic steel" [23]. Appertaining to that result, Besimo and co-workers stated in 1996 that the retention force of telescopic crowns is not significantly affected by the primary crown material [18].

In contrast to Besimo, Beuer *et al.* observed in 2010 that the surface roughness of the primary crowns affects the retention force of electroformed assemblies [19]. In their study, the Y-TZP primary crowns yielded higher retention load values with smoother surfaces. This interrelationship was explained by a smaller gap between the primary crown and coping [19], which can be achieved by a smoother surface after grinding and polishing [16]. In a recent 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) [24].

In the present study, Y-TZP and electroformed gold copings were used for secondary crowns. In this context, we found that groups with electroformed copings resulted in significantly lower retention load values as compared to Y-TZP groups, especially in the 0˝ taper configuration. This result is in accordance with recent studies, in which the combination of Y-TZP primary crown with an electroformed gold coping showed lower, more predictable and less excursive retention loads than conventionally cast telescopic crowns [9,14]. In another study, the galvanic copings yielded a better fit in comparison to casted ones [16]. The reason for this can be the small gap between the functional surfaces of the telescopic crown [16]. The automatic electroplating process achieves a smooth internal coping surface [16] and does not require any manually performed retention load adjustment [15].

Unfortunately, there exists no universal guideline for investigating telescopic crowns yet. Even the presence of saliva influences the results and increases retention load values [24]. Therefore, in the experimental setup, artificial saliva was used in all groups and each telescopic crown assembly was preloaded with 50 N as presented in literature [9,19,21]. Nevertheless, in this study, initial values were investigated. Advanced research about thermo-mechanical aging is necessary. Further limitations of the study are the lack of fatigue and clinical testing.

5. Conclusions

Considering the different taper angles, significant differences in two of four groups (C/Z, C/G) can only be noticed in the 1˝ group, evoked by the interaction of different materials and the design parameters of 1˝. With regard to the two primary crown materials, Y-TZP and CoCr, no significant differences of retention loads can be observed. If significant statistical differences occurred, electroformed copings showed lower retention load values compared to Y-TZP secondary crowns in each taper group.

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Author Contributions: Susanne Merk: fabricated and measured the specimens, wrote the manuscript; Patrick R. Schmidlin: experimental design, proofread the manuscript; Christina Wagner: assisted by specimen preparation, proofread the manuscript; Veronika Stock: assisted by retention force measurements, proofread the manuscript; Marlis Eichberger: supported the specimen fabrication; Malgorzata Roos: performed the statistical analyses, proofread the manuscript; Bogna Stawarczyk: idea, experimental design, data analyses and proofread the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ZrO_2	Zirconia
Y-TZP	Yttrium-stabilized tetragonal zirconium oxide
CoCr	Cobalt-chromium alloy
RL	Retention load
CAD/CAM	Computer-aided design/computer-aided manufacturing
FDPs	Fixed dental prostheses
RDPs	Removable partial dentures

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Zusammenfassung

Ziel: Das Ziel dieser Studie war es die Retentionskräfte zwischen Primärkronen aus Zirkonoxid (ZrO_2) und Sekundärkronen aus Polyetheretherketon (PEEK) mit unterschiedlichen Herstellungswegen und jeweils drei verschiedenen Konuswinkeln zu untersuchen.

Material und Methode: Standardisierte ZrO_2 Primärkronen wurden mit drei verschiedenen Konuswinkeln hergestellt: 0°, 1° und 2° (n=10/Gruppe). Jeweils 10 Sekundärkronen wurden aus PEEK Ronden (breCam Bio HPP blanks) gefräst (PM), aus industriell hergestellten PEEK Pellets (Bio HPP Pellet) gepresst (PP) und aus PEEK Granulat (Bio HPP Granulat) gepresst (PG). Alle Kronen wurden vom gleichen Anwender manuell nachbearbeitet. Von diesen insgesamt 90 Sekundärkronen wurden je zwanzigmal die Retentionskräfte in Abzugsversuchen mit einer Geschwindigkeit von 50mm/min gemessen. Zur Datenanalyse wurden einfache und zweifache Varianzanalysen, gefolgt von einem Scheffé Post-hoc-Test angewendet ($p<0.05$).

Ergebnisse: Bei einem Winkel von 0° erzielte die PP Gruppe höhere Retentionskräfte als die anderen Gruppen ($p=0.005$). Bei 1° Winkeln zeigte die PP Gruppe höhere Retentionskräfte als die PM Gruppe ($p<0.001$). Die Art der Pressverarbeitung zeigte keinen Einfluss auf die Ergebnisse. Innerhalb der 2° Gruppe hatte die Herstellungsmethode der PEEK Sekundärkronen keinen Einfluss auf die Retentionskräfte ($p=0.228$). Innerhalb der PM Gruppe zeigten die 2° Prüfkörper höhere ($p=0.020$) Retentionskräfte verglichen mit 1°-Gewinkelten. Ein Einfluss des Winkels kann innerhalb der PP Gruppe nicht beobachtet werden ($p=0.658$). Innerhalb der PG Gruppe zeigten die 0° Prüfkörper geringere Retentionskräfte als 1° ($p=0.009$), wobei 2° keine Unterschiede zeigten.

Schlussfolgerung: Die Herstellungsmethode der Sekundärkronen und der Konuswinkel ergaben keine einheitliche Wirkung auf die Retentionskräfte innerhalb aller Gruppen. Die Retentionskräfte betreffend scheint PEEK ein geeignetes Material für herausnehmbare Prothesen und Doppelkronen auf ZrO_2 Primärkronen zu sein.

materials

MDPI

Article

Suitability of Secondary PEEK Telescopic Crowns on Zirconia Primary Crowns: The Influence of Fabrication Method and Taper

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Abstract: This study investigates the retention load (RL) between ZrO_2 primary crowns and secondary polyetheretherketone (PEEK) crowns made by different fabrication methods with three different tapers. Standardized primary ZrO_2 crowns were fabricated with three different tapers: 0°, 1°, and 2° ($n = 10$/group). Ten secondary crowns were fabricated (i) milled from breCam BioHPP blanks (PM); (ii) pressed from industrially fabricated PEEK pellets (PP) (BioHPP Pellet); or (iii) pressed from granular PEEK (PG) (BioHPP Granulat). One calibrated operator adjusted all crowns. In total, the RL of 90 secondary crowns were measured in pull-off tests at 50 mm/min, and each specimen was tested 20 times. Two- and one-way ANOVAs followed by a Scheffé's post-hoc test were used for data analysis ($p < 0.05$). Within crowns with a 0° taper, the PP group showed significantly higher retention load values compared with the other groups. Among the 1° taper, the PM group presented significantly lower retention loads than the PP group. However, the pressing type had no impact on the results. Within the 2° taper, the fabrication method had no influence on the RL. Within the PM group, the 2° taper showed significantly higher retention load compared with the 1° taper. The taper with 0° was in the same range value as the 1° and 2° tapers. No impact of the taper on the retention value was observed between the PP groups. Within the PG groups, the 0° taper presented significantly lower RL than the 1° taper, whereas the 2° taper showed no differences. The fabrication method of the secondary PEEK crowns and taper angles showed no consistent effect within all tested groups.

Keywords: polyetheretherketone (PEEK); zirconia; telescopic crowns; computer-aided design/computer-aided manufacturing (CAD/CAM); retention load (RL)

1. Introduction

In prosthetic dentistry, metal and alloys are the most commonly approved materials [1]. Due to their excellent physico-mechanical properties, precious and non-precious metals are applied in fixed prosthodontics as well as in removable partial prosthodontics such as the double crown technique. While precious metals like gold are particularly well-tolerated, studies have shown that the biocompatibility might be problematic, especially in combination with other metals in the oral cavity [2]. The direct contact of different metals in the oral cavity, as well as metallic ions solved in saliva [3], may cause galvanic corrosion. This problem has been extensively investigated in several studies [2–6]. Even titanium, known for its corrosion resistance [3], may cause corrosion when used in so-called polymetallism [7]. This phenomenon was observed in a primate study with titanium implants combined with superstructures from precious alloys. Titanium can also develop cytotoxic effects, as shown in a recent study [4]. In contrast, the same study mentioned no cytotoxicity of zirconia implants [4].

ZrO_2, a ceramic material used for medical devices [8], displays good esthetic appearance, high mechanical strength, and high biocompatibility and is used in a wide range of indications, such as frameworks, implants, and abutments [9]. In addition, its very good long-term stability and reliability was proven in a 10-year clinical study [10]. These excellent material properties and the transformation behavior are explained by the yttrium oxide stabilization of ZrO_2 [8]. ZrO_2 has also been demonstrated as a material for primary crowns in the double crown technique and has featured itself as an alternative to a gold alloy [11]. In the case of primary crowns with a 0° taper, it even appeared to be better than gold alloys when comparing retention loads [11]. Another investigation of double crowns with different conus angles of 0°–6° [12] concluded that ZrO_2 primary crowns result in more predictable and less excursive retention loads and that the retention load increased as the conus angle decreased. In addition to the taper, the surface roughness also has an impact on retention load [13], and ZrO_2 with its low surface roughness is therefore well suitable. Moreover, the low surface roughness and low surface energy result in low biofilm accumulation, which not only applies to ZrO_2. A study found that implant abutments of PEEK showed equal or lower values of biofilm formation than those made of ZrO_2 and titanium [14].

Polyetheretherketone (PEEK), a modified polyetherarylketone (PEAK), is a thermoplastic high-performance polymer with a melting point of about 343 °C. The examined physical properties [15], abrasion resistance [16], high hardness, and low water absorption and solubility [17] render this material an interesting material for dentistry. In this field, there are three ways of converting the PEEK material: milling from blanks with computer-aided design/computer-aided manufacturing (CAD/CAM) software, pressing from granules, or pressing from pellets with a special vacuum-pressing device. Blanks and pellets are prepressed forms from the raw material PEEK granules.

PEEK as well as ZrO_2 represent both very biocompatible materials and are used for several applications, e.g., for dental implants [18], provisional abutments [19], and fixed dental prostheses (FDPs) [20]. However, for extending the field of indications, it was necessary to connect PEEK with other resin composite materials. Despite the resistance to surface modification, a suitable bond can be reached via etching and the use of MMA-containing coupling agents [21]. PEEK is also used for implant-supported bars and clamps for removable prostheses [18,19,22–24]. Furthermore, recent publications reported that PEEK is a suitable material for double crown systems [25–27]. Finally, a gold alloy with its ductility already affects good results in combination with ZrO_2 [12]. Therefore, a new concept could be the combination of these two biocompatible materials, i.e., ZrO_2 and PEEK in order to produce metal-free FDPs such as telescopic crowns. As a matter of fact, to the authors' knowledge, there are no existing published studies with regard to this topic—especially when aiming to assess the retention load between ZrO_2 primary crowns and secondary PEEK crowns made by different fabrication methods with three different tapers. The null hypotheses of this study were therefore to test that (i) the fabrication method and (ii) the taper have no influence on the retention load.

2. Material and Methods

In this study, the retention load of 90 double crowns was investigated. The primary crowns were made from ZrO_2 (Ceramill ZI 71; AmannGirrbach AG, Koblach, Austria, LOT: 1303002), whereas the secondary crowns were made from PEEK materials: (i) breCam BioHPP blanks (bredent, Senden, Germany, LOT: 394172) for CAD/CAM milling; (ii) BioHPP Pellet (bredent, Senden, Germany, LOT: 393554) for PEEK pellet pressing; (iii) BioHPP Granulat (bredent, Senden, Germany, LOT: 379806) for PEEK granular pressing. According to the manufacturer BioHPP is a ceramic-reinforced, partly crystalline polyetheretherketone (PEEK).

2.1. Fabrication of Specimens

First, a prepared plastic model tooth was used as a template for silicone molds (Adisil blau 9:1, Siladent, Goslar, Germany). Based on this master model, 30 wax (Milling- & Universal Wax blue; GEBDI, Engen, Germany) duplicates were manufactured and cast in a base metal alloy (Remanium GM800+; Dentaurum, Ispringen, Germany, LOT: 936) using a conventional casting method. These molar dies were scanned (Ceramill map 300, AmannGirrbach AG), and, based on these data sets, three master type primary crowns with tapers of 0°, 1°, and 2° were constructed (Ceramill mind, AmannGirrbach AG). All three constructions were designed with wall thicknesses of 2 mm. The samples with a taper of 0° received a chamfer preparation. Having milled each of the 10 primary crowns with 0°, 1°, and 2°, (Ceramill Motion 2 System, AmannGirrbach AG), these 30 ZrO_2 primary crowns were sintered (Ceramill therm, AmannGirrbach AG) with the following program: a heat-up phase to a final temperature of 1450 °C (heating rate 5–10 K/min), 2 h dwell time at this temperature, and finally a cooling phase to room temperature (at least <200 °C), approx. 5 K/min.

The next step was an adhesive cementation process of the ZrO_2 primary crowns on the metal dies with self-adhesive resin cement (RelyX Unicem 2, 3M ESPE, Seefeld, Germany, LOT: 509981). Afterwards, they were aligned in a parallel fashion and based in a plaster socket to ensure their ideal position during pull-off testing. Afterwards, they were all manually reworked in a surveyor device (parallelometer F4 basic, DeguDent, Hanau, Germany) by a calibrated operator to ensure their individual taper angles. Therefore, diamond burs with appropriate tapers and a turbine (W & H Perfecta 900, W & H Dentalwerk Bürmoos GmbH, Bürmoos, Austria) were used under constant water cooling. The diamond processing occurred gradually from coarse (grit size 151 μm) to middle (grit size 107 μm) to fine grit (grit size 46 μm; Ceramic Art Set 4371/4369, ZR374M/F, Komet Dental, Lemgo, Germany; all grit sizes according to the manufacturer's data). The surface was first polished with a 3-step silicone polish system (Ceramic Art Set 4371, Komet Dental) and finished with round brushes (Komet Dental, REF: 9638900190) and polishing paste (YETI DIA-GLACE; YETI Dentalprodukte GmbH, Engen, Germany, Pat. 3832085.1) for a high gloss. Due to this individualization, 30 primary crowns resulted, and each one was individually scanned (Arti-Spray, white, BK 285; Dr. Jean Bausch KG, Cologne, Germany; Ceramill map 300, AmannGirrbach AG).

On this basis, constructions for the secondary crowns were designed and milled out of these data (ZENO Tec System, ZENO 4030 M1, Wieland + Dental, Pforzheim, Germany), i.e., 30 specimens from PEEK blanks (Figure 1) (breCAM BioHPP, bredent, LOT: 394172) (PM) and 60 specimens from wax blanks (breCAM.wax; bredent, LOT: 382697). The latter were randomly divided in two groups—30 specimens for the production from pellets (PP) and 30 specimens for the production from granules (PG).

Afterwards, they were embedded in a muffle (5–6 wax models together) with a mixing ratio of 70% liquid/distilled water (Bresol for 2 press liquid, bredent, LOT: 1; Brevest for 2 press, bredent, LOT: 1) for 25 min according to the manufacturer's instructions. The muffle and a press plunger (for 2 press filler, bredent, LOT: 397014) were placed in a 850 °C preheated furnace for 60 min, which was cooled down afterwards with 8 °C/min to 400 °C. After a waiting period of 20 min at this temperature, PEEK granular and pellets (Bio HPP Granulat/Pellet, bredent) were filled into the melt reservoir of the muffle. The melting period accounted for 20 min. The muffle with the melted PEEK and the positioned press plunger was placed onto the pressing table of the pressing device and was manually closed (vacuum pressing device for 2 press; bredent). The vacuum press process with a pressure of 4.5 bar ran automatically (Figure 2).

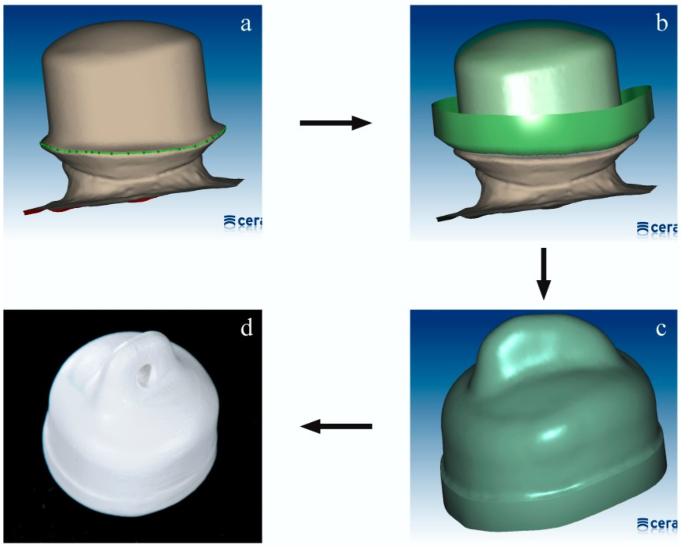

Figure 1. Photo series about CAD/CAM processing a PEEK secondary crown (PM) (**a**) scanned primary crown (0° taper), marked preparation border; (**b**) secondary crown construction; (**c**) setup-wizard of secondary crown with designed retainer; (**d**) milled secondary crown, end result.

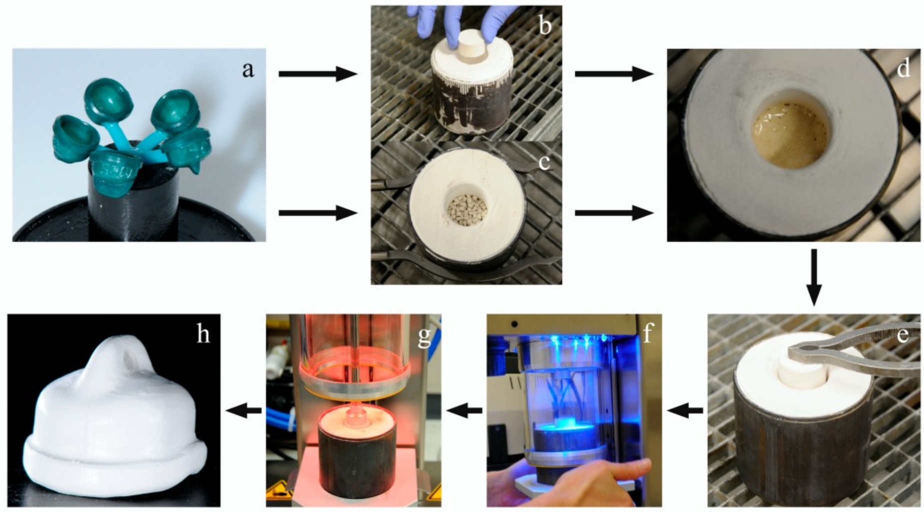

Figure 2. Photo series about processing from wax model to PEEK secondary crown (PP/PG) (**a**) 5 wax models (secondary crowns) on the muffle plate, prepared for embedding; (**b**) one piece PEEK pellet, put into a preheated muffle (melting reservoir); (**c**) PEEK granular filled into a preheated muffle; (**d**) PEEK material in its melted phase (about 380 °C); (**e**) preheated press plunger positioned into the melting reservoir; (**f**) pressing device during manually closing; (**g**) ending of the pressing process: pressure was kept while cooling down; (**h**) pressed PEEK secondary crown, end result.

After divesting all specimens, they were air-abraded (Fine-blaster type FG 3, Sandmaster, Zofingen, Switzerland) with 50 μm of Al_2O_3 (Hasenfratz, Sandstrahltechnik, Aßling, Germany) at a pressure of 2 bar. Fitting of every secondary crown (PM/PP/PG) to their primary crown was tested by a calibrated operator using articulation spray (Arti-Spray, white, BK 285, Dr. Jean Bausch KG, Cologne, Germany) and adjusted using cross-cut burs (Komet Dental, LOT: 277889) where necessary. Silicone polishers (Ceragum Wheel, bredent, REF: PRKM22000) and polishing brushes (Komet Dental, LOT: 226983) with polishing paste (Abraso-Starglanz asg, bredent REF: 52000163) were used to finish the specimens.

2.2. Retention Load Measurement

For retention load measurement, a pull-off test setup was created (Figure 3). The socketed die with its primary crown was fixed in a universal testing device (Zwick 1445, Zwick, Ulm, Germany). The secondary crown was wetted with artificial saliva (Glandosane, cell pharm GmbH, No. 9235461109) and placed in a final position onto the respective primary crown. In each of the 20 cycles, a 5 kg weight was put on top for 20 s to ensure a comparable starting situation for each specimen. The secondary crown was pulled off with a speed of 50 mm/min [25–29] using a hook that was mounted in the designed retainer.

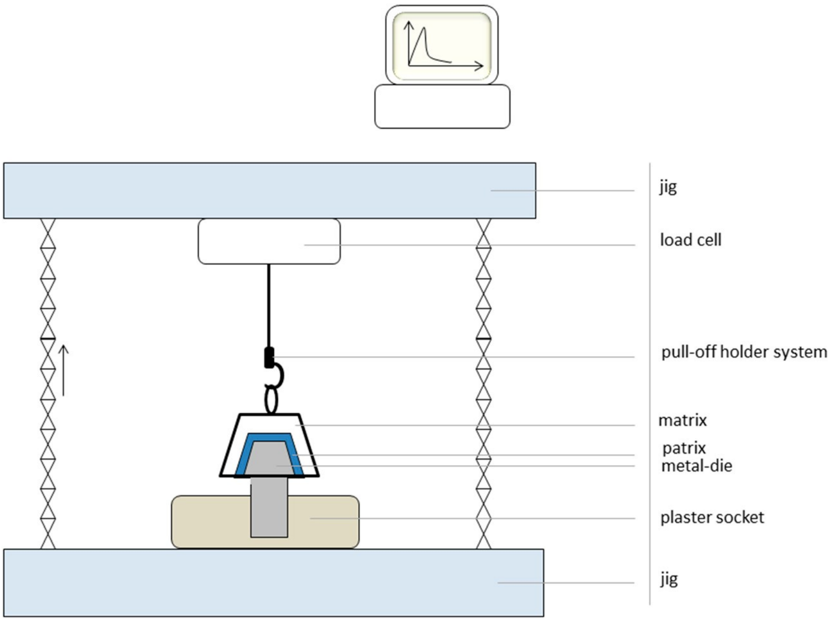

Figure 3. Test design.

2.3. Statistical Analyses

A Kolmogorov–Smirnov test was used to verify the normality of data distribution. Descriptive statistics (mean, standard deviation (SD), 95% confidence intervals (CI), minimum, median, and maximum) were computed. Significant differences between the groups were tested with 2-way and 1-way ANOVAs, followed by the Scheffé's post-hoc test. All statistical tests were calculated using IBM SPSS (Version 20; IBM Corporation, Armonk, NY, USA) ($p < 0.05$).

3. Results

The cycles presented no impact on the resulting measurements of each specimen ($p = 0.354$); therefore, arithmetic means were computed. The descriptive statistics are summarized in Table 1. The Kolmogorov–Smirnov test indicated no evidence of a violation of the normality assumption in the data ($p < 0.05$). According to the two-way ANOVA, the results showed that the fabrication methods ($p = 0.144$) as well as the taper type ($p = 0.958$) had no effect on the retention load results. However, the interaction between both parameters was significant ($p = 0.001$). Subsequently, the data was split and analyzed with respect to the test hypotheses individually (Table 1).

Table 1. Descriptive statistics such as mean with standard deviation (SD), 95% confidence intervals (95% CI), and the robust statistics (minimum/median/maximum). All values for retention load are presented in Newton (N).

Taper Angle	Material Group	Mean ± SD	95% CI	Min/Median/Max
0°	PM	13.83 ± 7.82 $^{ab/A}$	(8.1; 19.5)	2.8/13.0/28.0
	PP	22.83 ± 5.94 $^{a/B}$	(18.4; 27.1)	16.9/21.4/33.1
	PG	15.87 ± 2.58 $^{a/A}$	(13.9; 17.8)	12.5/15.8/20.2
1°	PM	6.07 ± 3.01 $^{a/A}$	(3.8; 8.3)	1.7/6.8/9.6
	PP	21.06 ± 8.60 $^{a/B}$	(14.8; 27.3)	11.2/21.9/31.7
	PG	27.00 ± 10.05 $^{b/B}$	(19.7; 34.2)	11.3/26.9/46.5
2°	PM	14.10 ± 8.19 $^{b/A}$	(8.1; 20.0)	7.2/11.2/34.7
	PP	19.84 ± 7.13 $^{a/A}$	(14.6; 25.0)	9.6/18.8/29.4
	PG	19.05 ± 8.25 $^{ab/A}$	(13.1; 25.0)	5.3/18.4/31.9

PM: PEEK milled; PP: PEEK pressed pellet; PG: PEEK pressed granular; ^{a,b}: differences between the taper angles within one material group; ^{A,B}: differences between the material group within one particular taper.

By comparison of the fabrication method within 0° crowns showed that the pellet pressed group displayed significantly higher retention load values compared with the other groups (p = 0.005). Among the 1° taper, the milled secondary crowns had significantly lower retention load values than the pressed groups (p < 0.001). However, the pressing type had no impact on the results. The groups with the 2° taper presented no effect on the fabrication method (p = 0.228).

Within milled PEEK secondary crowns, a 2° taper showed significantly higher retention loads compared with a 1° taper (p = 0.020). A taper with 0° was in the same range of values as compared to the 1° and 2° taper. No impact of taper on retention values was observed between the pressed secondary crowns from the PEEK pellet material (p = 0.658). In contrast, the pressed crowns from the granular 0° taper presented significantly lower values than the 1° ones (p = 0.009), whereas the 2° taper showed no differences.

4. Discussion

To the authors' knowledge, no studies of the combination of ZrO_2 and PEEK with the double crown technique have been published. Therefore, this study was aimed at investigating the retention load of ZrO_2 primary and PEEK secondary crowns.

The null hypothesis regarding the fabrication method of PEEK material must be rejected since the statistical evaluation showed differences between PM, PP, and PG. For instance, in the 1° taper group, milled PEEK specimens showed significantly lower retention loads than both pressed groups. This might be explained by differing fabrication procedures. On the one hand, there are specimens (primary and secondary crown) influenced only by CAD/CAM fabrication processes (PM); on the other hand, there are specimens (PP/PG) influenced by the pressing process. With CAD/CAM processing, the specimens are less subjected to unpredictable manufacturing aspects and bias. The main fact is to determine software parameters for designing the secondary crowns. In contrast, the pressing process entails passing several steps, such as embedding the wax models, heating the muffle and the PEEK material, letting it cool down, and allowing air-abrasion during the divesting process.

A recent report of a study on the fracture load of FDPs noted an influence of the fabrication method on PEEK material properties [20]. As a result, PEEK granular showed an incomplete fracture and a plastic deformation, in contrast to PEEK blanks and pellets. This study attributed this to the industrial prepressing processes, which increase mechanical properties. PEEK granular passes no prepressing, whereas PEEK blanks and pellets are extruded out of PEEK granular [20]. However, in this investigation, the specimens pressed from PEEK pellets showed a significantly higher retention load compared with those pressed from granules and the milled ones among the 0° taper group. PEEK blanks/granular were heated once. The blanks were heated during industrial fabrication by extruding out of granular and the PEEK granular just before pressing. It is supposed that the two heating processes of PEEK pellets—extruding and heating just before pressing—change the material properties and therefore the telescopic fitting. Due to these facts, it is suggested that the number of heating processes influences the retention load, whereas industrial prepressing considerably influences the fracture load.

The null hypothesis regarding the taper can be rejected because the taper has an impact on the retention load, especially in consideration of the milled and granular groups. Former studies showed that retention load decreases with the increase in the taper [12,30]. In contrast, this pattern could not be observed in this study. A reason could be the low flexural modulus of PEEK material amounting to only 4 GP [15]. This could lead to a growing wedging of primary and secondary crowns in tapered groups, while adapting them with a 5 kg weight, whereas almost no wedging occurs in 0° double crowns due to the parallelism and their chamfer with a final stop. These facts are reflected in lower retention load values of the 0° taper compared with the 1° taper in the granular group on the one hand, and lower retention load values of the 1° taper compared with the 2° taper in the milled group on the other.

Furthermore, in this study the interval between cone angles is altogether only 2 degrees (just 1° each). That is why retention load values regarding the taper are not significantly different in every case. However, a major study concluded that the cone angle of a telescopic crown should be less than 2 degrees for long-term use [30]. It can be suggested that the recommended clinical retention load values may be achieved by reducing the tread area. Nevertheless, the results of the present investigation seem to be suitable for using telescopic crowns, although long-term studies with clinical conditions are required.

5. Conclusions

In assessing retention load, PEEK may be a suitable material for removable prosthesis and a telescopic crown technique when used on zirconia crowns. However, long-term investigations and the advancement of PEEK CAD/CAM processing are still necessary.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PEEK	polyetheretherketone
PEAK	polyetherarylketone
CAD/CAM	computer-aided design/computer-aided manufacturing
RL	retention load
ZrO_2	zirconia
MMA	methyl methacrylate
FDPs	fixed dental prostheses
Al_2O_3	aluminum oxide

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3 Diskussion

In diesem Abschnitt werden die jeweiligen Arbeiten einzeln diskutiert.

3.1 Retentionskräfte verschiedener Doppelkronen-Kombinationen: Primärkronen aus Y-TZP und Kobalt-Chrom mit Sekundärkronen aus Y-TZP und Galvanokäppchen

Diese Untersuchung testet die Retentionskräfte verschiedener Doppelkronen-Kombinationen mit drei verschieden Winkeln: 0° mit Hohlkehle, 1° und 2° mit Tangentialrand. Zwei verschiedene Materialien wurden für die Primärkronen verwendet: Y-TZP und CoCr. Beide wurden CAD/CAM gefräst, anschließend gesintert und weisen vergleichbare Elastizitätsmodule auf. Jede Primärkrone wurde kombiniert mit einer Sekundärkrone aus Y-TZP und einem Galvanokäppchen.

Die erste Nullhypothese hinsichtlich des Winkels ist widerlegt, da die beiden Doppelkronen-Kombinationen C/Z und C/G mit 1° signifikant höhere Retentionskraftwerte zeigten als welche mit 0° und 2°. Wie eine frühere Studie zeigt [32] könnte das Design der Primärkrone grundsätzlich einen Einfluss auf die Retentionswerte haben. Laut Beuer et al. [32] benötigen Teleskopkronen mit 0° eine Hohlkehle, um Adhäsion zu schaffen, welche aber wiederum die Retentionskraft negativ beeinflusst.

Allgemein bekannt treten mit abnehmenden Winkeln höhere Retentionskräfte auf. Diese Aussage, basierend auf anderen Studien [18, 33, 34], steht zunächst im Gegensatz zu unseren Resultaten. Jedoch wurden dazu in der Literatur Winkel von 0° bis 6° untersucht. Turp et al. [18] weisen darauf hin, dass statistisch signifikante Unterschiede nur mit Winkelunterschieden von mehr als 2° auftreten. Diese Feststellung wird durch die vorliegende Arbeit bestätigt. Speziell durch die Gruppen Z/Z und Z/G, welche keine signifikanten Unterschiede der Retentionskräfte zwischen den drei Winkelgruppen 0°, 1° und 2° zeigten. Allerding empfiehlt die Arbeitsgruppe um Güngör et al. [33] für die Langzeitnutzung den Winkel von 2° nicht zu überschreiten. Höhere Retentionskraftwerte für 1° wurden in einer kürzlich durchgeführten Studie bestätigt [35]. Die Autoren untersuchten Winkel im Bereich von 0° bis 2° und beobachteten ebenfalls höhere Retentionswerte für Teleskopkronen mit 1°.

Die zweite Nullhypothese wird angenommen, da keine signifikanten Unterschiede zwischen den Gruppen mit verschiedenen Primär- und gleichen Sekundärkronen (C/Z und Z/Z; C/G und Z/G) gefunden werden konnten. In dieser Studie haben die beiden Primärkronenmaterialien vergleichbare Elastizitätsmodule (204 GPa Für Y-TZP und >200 GPa für CoCr). Bereits 1975 bezeichnete Garvie [36] ZrO_2 als "keramischen Stahl". Passend zu diesem Ergebnis stellten Besimo et al [37] später fest, dass die Retentionskraft von Doppelkronen nicht signifikant vom Primärkronenmaterial abhängig ist.

Im Gegensatz zu Besimo beobachtete 2010 Beuer et al [32] einen Einfluss der Oberflächenrauhigkeit der Primärkrone bei Galvano-Doppelkronen. In seiner Studie erzielten die Y-TZP Primärkronen, mit ihren glatteren Oberflächen, höhere Retentionskraftwerte. Dieser Zusammenhang wurde mit einem kleineren Spalt zwischen Primärkrone und Goldkäppchen erklärt [32], welcher durch eine glattere Oberfläche nach Beschleifen und Polieren erreicht werden kann [7]. In einer aktuellen Studie wird erklärt, dass Friktion generell von der Oberflächenrauhigkeit (R_a) des Materials (ZrO_2: R_a=0,02 µm, CoCr: Ra=0,44 µm) abhängt [38].

In der vorliegenden Untersuchung wurden Y-TZP und Goldkäppchen als Sekundärkronen verwendet. In diesem Zusammenhang wurde beobachtet, dass Gruppen mit Goldkäppchen im Vergleich zu Y-TZP Gruppen geringere Retentionskräfte ergaben, vor allem in der 0°-Konfiguration. Dieses Ergebnis steht im Einklang mit neueren Studien. Dort erreichte die Kombination von Y-TZP Primärkronen mit Galvanokäppchen geringere, vorhersehbarere und weniger sprunghafte Retentionswerte als konventionell gegossene Teleskopkronen [18,31]. In einer anderen Studie erzielten die Galvanokäppchen eine bessere Passung als gegossene Doppelkronen [7]. Grund dafür könnte der geringe Spalt zwischen den funktionellen Oberflächen der Doppelkrone sein [7]. Der automatische Galvanisierungsprozess ermöglicht eine glatte Käppcheninnenfläche [7] und erfordert keine manuelle Nachbearbeitung [6]. Unglücklicherweise gibt es bisher keine allgemeine Richtlinie zur Untersuchung von Doppelkronen. Auch das Vorhandensein von Speichel beeinflusst die Ergebnisse und erhöht die Retentionskraftwerte [38]. Daher wurde im Versuchsaufbau bei allen Gruppen Kunstspeichel verwendet und jede Doppelkrone mit 50 N vorbelastet, wie in der Literatur beschrieben [18, 32, 34]. Dessen ungeachtet wurden in dieser Studie nur Initialwerte untersucht. Weitere Einschränkungen dieser Studie sind das Fehlen von Ermüdungstests und klinische Untersuchungen.

3.2 Retentionskräfte zwischen Primärkronen aus Zirkonoxid (ZrO2) und Sekundärkronen aus Polyetheretherketon (PEEK) mit unterschiedlichen Herstellungswegen und jeweils drei verschiedenen Konuswinkeln

Nach Wissen der Autoren sind bisher keine Studien über Doppelkronen aus ZrO_2 und PEEK veröffentlicht. Daher war es das Ziel von dem 2. Teil der Dissertation, die Retentionskräfte zwischen ZrO_2 Primärkronen mit PEEK Sekundärkronen zu untersuchen.

Die Nullhypothese bezüglich der Herstellungsmethode von PEEK muss abgelehnt werden, da die statistische Auswertung Unterschiede zwischen PM, PP und PG ergab. Zum Beispiel zeigten in der 1°-Gruppe gefräste PEEK-Prüfkörper signifikant geringere Retentionswerte als die beiden gepressten Gruppen. Das könnte durch die verschiedenen Herstellungsmethoden erklärt werden. Einerseits gibt es Prüfkörper (Primär- und Sekundärkrone), die nur durch den CAD/CAM Herstellungsprozess beeinflusst sind (PM); andererseits gibt es Prüfkörper (PP, PG), welche durch den Press-Prozess beeinflusst sind. Mit der CAD/CAM-Verarbeitung sind die Prüfkörper weniger den unvorhersehbaren handwerklichen Aspekten ausgeliefert. Der wichtigste Faktor ist die Bestimmung der Softwareparameter zum Designen der Sekundärkronen. Der Pressprozess ist im Gegensatz dazu mit einigen Herstellungsschritten wie dem Einbetten der Wachsmodelle, dem Aufheizen der Muffel und des PEEK Materials, dem Abkühlungsvorgang und dem Korundstrahlen beim Ausbetten verbunden.

Eine neuere Studie [23] zu Bruchlast von dreigliedrigen Brücken stellte einen Einfluss der Herstellungsmethode auf die Materialeigenschaften von PEEK fest. Resultierend zeigte PEEK Granulat einen inkompletten Bruch und plastische Deformation, im Gegensatz zu PEEK Ronden und Pellets. Diese Studie schreibt dies dem industriellen Vorpressen zu, welches die mechanischen Eigenschaften verstärkt. PEEK Granulat durchläuft kein Vorpressen, während PEEK Ronden und Pellets aus PEEK Granulat extrudiert werden [23]. Allerdings zeigten in dieser Dissertation innerhalb der 0° Gruppe die gepressten Prüfkörper aus PEEK Pellets signifikant höhere Retentionswerte als PG und PM. Es wird vermutet, dass die beiden Aufheizvorgänge von PEEK Pellets - beim extrudieren und beim Aufheizen vor dem Pressen - die Materialeigenschaften verändern PEEK Ronden und Granulat werden ein einziges Mal erhitzt. Die Ronden werden während des industriellen Strangpressens aus PEEK Granulat erhitzt und das Granulat vor dem Pressvorgang und dadurch auch die Teleskoppassung. Daher wird angenommen, dass die Zahl der Heizprozesse die Retentionskraft beeinflusst, während das industrielle Vorpressen eine erhebliche Auswirkung auf die Bruchlast hat.

Die Nullhypothese hinsichtlich des Winkels wird abgelehnt, da der Winkel einen Einfluss auf die Retentionskraft besitzt, insbesondere bei der Betrachtung der Fräs- und Granulatgruppen. Frühere Studien zeigten, dass die Retentionskraft mit abnehmenden Winkel steigt [18, 34]. Dieses Muster kann allerdings in dieser Dissertation nicht beobachtet werden. Ein Grund dafür könnte der kleine E-Modul von PEEK mit nur 4 GPa sein [27]. Dies könnte bei den 1° und 2° Gruppen zu einem verstärkten Verkanten von Primär- und Sekundärkrone führen, während sie mit einem 5 kg-Gewicht adaptiert werden. Bei den 0° Doppelkronen kommt es wegen der parallelen Wände und der Hohlkehle mit finalem Stopp nicht zur Verkantung. Dieser Sachverhalt spiegelt sich in geringeren Retentionswerten für 0° Prüfkörper verglichen mit 1° Prüfkörpern innerhalb der Granulat Gruppe einerseits wieder und andererseits in geringeren Retentionswerten für 1° im Vergleich zu 2° innerhalb der Fräsgruppe.
Eine vielbeachtete Studie schlussfolgert, dass der Winkel für die Langzeitnutzung nicht kleiner als 2° sein sollte [34]. In der vorliegenden Dissertation beträgt das Intervall zwischen den Konuswinkeln allerdings insgesamt nur 2° (dementsprechend jeweils nur 1° Intervalle). Daher sind die Retentionswerte hinsichtlich des Winkels vermutlich nicht signifikant unterschiedlich. Es kann behauptet werden, dass die für die Klinik benötigten Retentionskräfte durch Verkleinern der Lauffläche erreicht werden können. Trotzdem deuten die Ergebnisse dieser Studie auf die Eignung von PEEK für Teleskopkronen hin, auch wenn noch Langzeitstudien mit klinischen Bedingungen notwendig sind.

4 Zusammenfassung und Ausblick

Die vier untersuchten Dentalmaterialien zeigten stabile Retentionskräfte in dieser Initialtestung und erwiesen sich als geeignete Materialien für Doppelkronensysteme. Als entscheidendes Ergebnis zeigte sich, dass das Material der Primärteile keinen Einfluss auf die Retentionskräfte hatte. Für den klinischen Alltag bedeutet dies, dass die Materialentscheidung nicht vom Primärteil ausgehen muss. Hingegen sollte das Augenmerk auf die Materialpaarung von Primär- und Sekundärteil gelegt werden. Nicht jede dieser in-vitro untersuchten Materialpaarungen kann uneingeschränkt klinisch verwendet werden. Beachtet werden sollten der Anspruch des Patienten auf Ästhetik, bestehende Allergien, finanzielle Mittel und mögliche weitere Anforderungen. Weiterhin sollten eventuell vorhandene andere Metallrestaurationen im Mund berücksichtigt werden, um die Verwendung vieler verschiedener Metalle zu vermeiden. Auch die Material- und Verarbeitungskosten sind entscheidend für die Auswahl der Teleskopmaterialien. Kostspielige, bewährte Varianten aus Gold konkurrieren mittlerweile mit kostengünstigeren, bioinerten PEEK-Produkten.

PEEK kann mit jeder der drei untersuchten Herstellungsmethoden verarbeitet und in der Praxis angewendet werden. Im Bereich von 0° bis 2° scheint der Winkel nicht maßgeblich zu sein. Die CAD/CAM-Verarbeitung musste bezüglich der Fräsparameter noch optimiert werden. Gefräste Prüfkörper zeigten etwa eine erhöhte Streuung der Retentionskraftwerte. Dessen ungeachtet ist die CAD/CAM-Verarbeitung dieses hochmodernen Werkstoffes jedoch vorhersehbarer als die konventionelle Technik des Pressens. Zusammenfassend kann gesagt werden, dass bezüglich der Retentionskräfte PEEK ein geeignetes Material für herausnehmbare Prothesen und Doppelkronen mit ZrO_2 Primärkronen ist.

Ebenfalls CAD/CAM verarbeitet zeichnet sich ZrO_2 durch hohe Festigkeit, Biokompatibilität und Ästhetik aus. Diese hochfeste Keramik hat sich daher bereits in der modernen Zahnmedizin etabliert. ZrO_2 kann unter anderem als Primärteil, Sekundärteil und als homogene Teleskoppaarung verwendetwerden.

Die Teleskoppaarung ZrO_2 /PEEK ist durchaus eine interessante Alternative zu den herkömmlichen Varianten, sollte sich allerdings auch noch in klinischen Langzeitstudien beweisen.

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7 Arbeiten der Forschungsgruppe

Folgende Arbeiten der Forschungsgruppe wurden bereits veröffentlicht.

1. **Merk S**, Wagner C, Stock V, Schmidlin PR, Roos M, Eichberger M, Stawarczyk B. Retention load values of telescopic crowns made of Y-TZP and CoCr with Y-TZP secondary crowns: Impact of different taper angles. Materials. 2016; 5: 354. doi:10.3390/ma9050354
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