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Publications on Pekkton®

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Dental

Publications on Pekkton®.

1. Copponnex T., DeCarmine A.: Reevaluating Thermoplastics. European Medical Device Manufacturer, March/April 2009.

2. Copponnex T.: Like a chameleon. Medical Device Developments, 2010.

3. Copponnex T., Blümli M.: New material approaches in dental technology. meditec, October 2011.

4. Fuhrmann G., Steiner M., Freitag-Wolf S., Kern M.: Resin bonding to three types of polyaryletherketones (PAEKs) – Durability and influence of surface conditioning. Dental Materials 2014 Mar;30(3):357-63.

5. Gobert B.: C'est quoi le PEKK? Technologie Dentaire 2014 n° 166.

6. Gobert B.: Faux moignon anatomique en Pekkton®. Technologie Dentaire 2014 n° 166.

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9. Tannous F., Steiner M., Shahin R., Kern M.: Retentive forces and fatigue resistance of thermoplastic resin clasps. Dental Materials 2012 Mar;28(3):273-8.

1.

Copponnex T., DeCarmine A.:
Reevaluating Thermoplastics.
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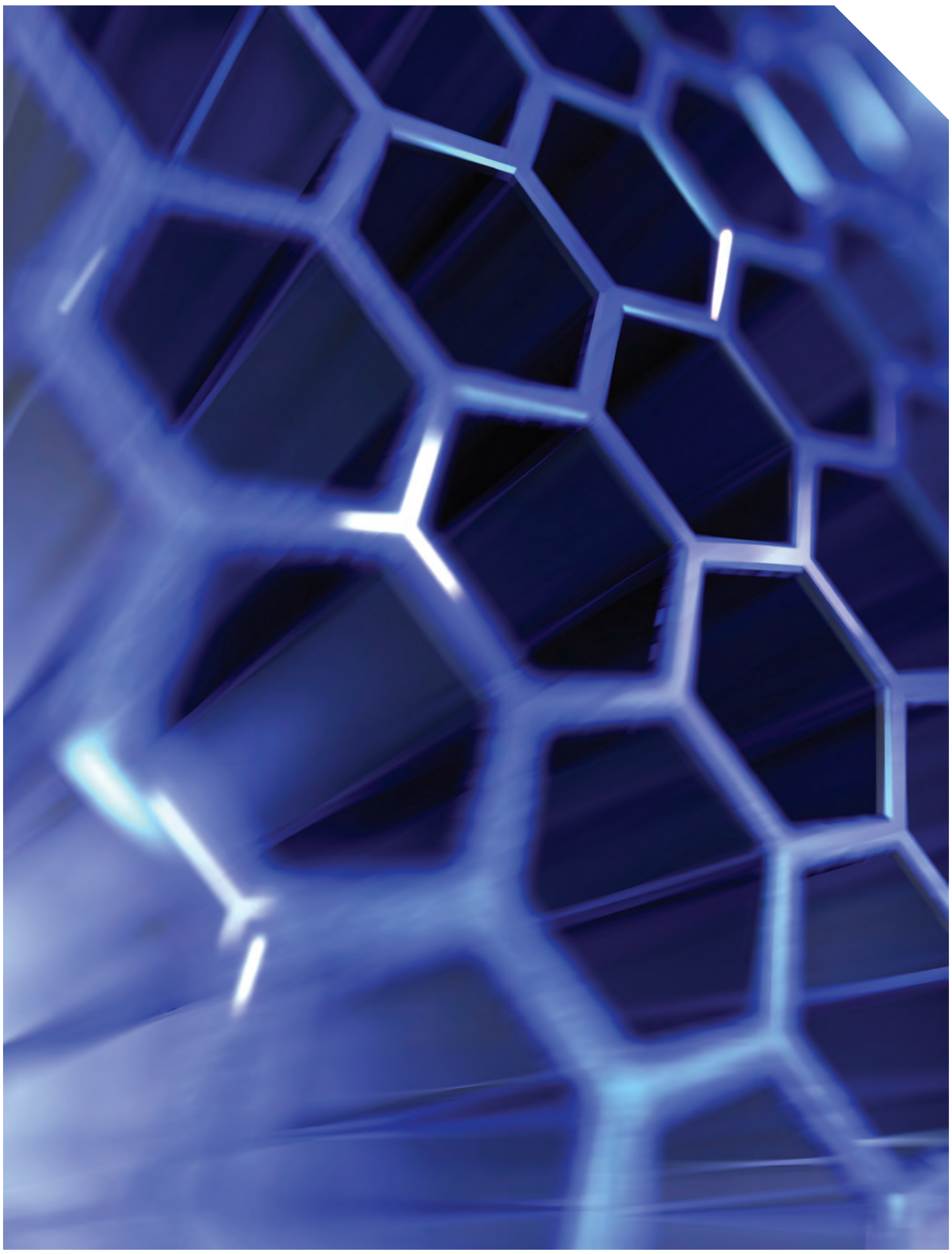
Reevaluating Thermoplastics

How good is PEEK, really, for aesthetic and long-term structural applications?

Thierry Copponnex and Anthony DeCarmine



Titanium, ceramics such as zirconia and precious metal alloys are commonly used in long-term dental applications. Each material family has specific advantages: the strength of titanium is preferred for dental implants, whereas zirconia is used mainly for crowns and bridges because of its aesthetic qualities.

Polyetheretherketones (PEEK) have been gaining favour over the last few years as alternative materials for some temporary applications. Nonstructural products made from nonreinforced-fibre PEEK, such as healing caps and provisional abutments, are currently available from various suppliers. These new materials strike an advantageous balance of strength, proven biocompatibility, aesthetics, versatility in manufacturing and flexibility in the end-use environment (meaning the dentist can modify the product during surgery, if required). This material has gained wide acceptance in the dental field, as evidenced by the number of PEEK-based products that are available today. There is, however, a general misunderstanding about PEEK.

Distracted, perhaps, by PEEK's novelty, users may neglect to take into account the entire polyaryl polymer family. While PEEK is the most representative member of the material family, it may not be the optimal choice for dental applications, where aesthetic considerations and long-term structural properties are of primary importance. Products made from polyetherketoneketone (PEKK) may be a better option.

The specific mechanical properties of polyaryl polymers are a product of the material's structural backbone, which gives a similar signature to all of the polymers in the polyaryl family. For that reason, neat PEEK and PEKK resins both share astonishing mechanical, chemical and physical properties.

Preventing Degradation

While it is well known that the interface between carbon fibres and polyaryl matrices is not adversely affected by aqueous liquids, such is not the case with glass fibres. To maintain aesthetics in long-term applications, the material's mechanical properties must be specifically tailored with the adjunction of reinforcing glass fibres. The glass fibres receive a surface treatment to enable them to reinforce polymers with moderate temperature resistance. Because of the approximate 400°C processing temperatures required by PEEK and PEKK thermoplastics, weaknesses may occur at the interface of the glass fibre and polymer matrix, leading to possible degradation. As a result, the ability of glass fibre–reinforced polyaryl composites to withstand daily exposure to a wet environment in the oral

Figure 1. Fibre-reinforced fixed bridge bending test.

cavity over a long period of time requires monitoring. If the interface is degraded, the product's shear and compressive strengths will be most affected, but the degradation will also have an impact on stiffness.

Table I shows how mechanical properties are affected when PEEK and PEKK glass-reinforced composites are immersed in 50°C water for nine months. For comparison purposes, the percentage of relative loss in properties is also indicated. These results (reported elsewhere) indicate a clear drop in both the strength and stiffness of reinforced PEEK. Flexural stiffness is reduced by a factor of 2 in reinforced PEEK, while there is only a slight leveling off in reinforced PEKK. There is also a stark difference in the way in which an aqueous environment affects the compressive strength of PEEK and PEKK. In the case of PEKK, it is statistically unchanged. These results are of primary importance for long-term structural applications, and raise serious questions about the use of PEEK-based products.

Cycles	Relative fracture load (%)	Estimative time
2'500	100	½ week
10'000	88	15 days
100'000	80	5 months
250'000	75	1 year

Table II. Fatigue testing for short-fibre reinforced PEKK bridges

	Short Beam Shear Strength MPa		90° Flexural Strength MPa		90° Flexural Modulus GPa		Compressive Strength MPa	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
PEEK-GF	98.6	29.7	65.5	24.1	9.0	4.8	981	439
PEKK-GF	82.7	66.2	75.2	52.4	16.6	14.5	957	992

Table I. The effect on mechanical properties when PEEK and PEKK glass-reinforced composites are immersed in 50°C water for nine months. (Adapted from Rapra Review Report.)

Fatigue testing of short-fibre-reinforced PEKK bridges is shown in Table II. The short glass fibre–reinforced PEKK bridges sustain a 75% relative fracture load. This result inspires confidence for high-strength applications with more specific reinforcements.

Figure 1 illustrates the fatigue bending test of a short-fibre-reinforced bridge. First experiments were carried out under dry (26°C) and wet conditions (Ringer's solution at 37°C). Even after 250,000 cycles (simulating a one-year load), the glass-reinforced PEKK bridges were shown to sustain a substantial portion of the fracture load after as few as 1000 cycles, according to Dr. Thomas Hug, Project Manager, Cendres+Métaux SA.

In conclusion, PEKK resins have an enormous advantage over PEEK materials in long-term dental applications when polyaryl matrices are exposed simultaneously to repeated stress and a wet environment. PEKK resins, in our view, will contribute to the development of successful products that will provide structural and aesthetic satisfaction. ■

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Anthony DeCarmine
is an engineer with more than 20 years of experience in the industrial (textile manufacturing), aerospace (space systems) and engineered materials (ceramics and polymers) spheres. He is currently Technical Director at Oxford Performance Materials (Enfield, CT, USA), a group specialising in the development and commercialisation of applications using the ultra-high-performance polymer OXPEKK.

2.

Copponnex T.:
Like a chameleon. Medical Device Developments, 2010.

Like a chameleon

While polymers have a long history of use in the dental industry, the highly-adaptable Pekkton from **Cendres+Métaux** has a wider range of applications.

An example of a three-unit Pekkton bridge with veneering.

Titanium, precious metal alloys and ceramics, such as zirconia, are commonly used in long-term dental applications. Each material has specific advantages: the strength of titanium is preferred for dental implants; the physical and mechanical properties of precious metals work well in ceramo-metallic crown and bridge reconstructions, while the aesthetic properties of zirconia are unsurpassed. Recently, other materials have established themselves in the dental industry: fibre-reinforced thermoplastics, such as polyetheretherketones (PEEK).

Over the past decades, polymers – whether thermoset or thermoplastic – were already widely employed in dentistry. However, they were mainly used in temporary applications. In terms of colours, polymers can be adapted to dental demands, making them a popular choice while, for industrial production, non-structural products made from non-reinforced fibre, PEEK, are also available, for example healing caps and provisional abutments. These new materials strike an advantageous balance of strength, biocompatibility, aesthetics and versatility in manufacturing. They have gained wide acceptance in the dental field as can be seen by the number of PEEK-based products available today.

Adapting to different structures

However, PEEK might not be the optimal choice for dental applications where aesthetic and long-term structural properties are of primary importance. Because of its crystalline structure, PEEK's performance is limited, and the complex manufacturing process needs fingertip accuracy. However, Pekkton, based on another member of the polyaryletherketone family, polyetherketoneketone (PEKK), has been specifically developed for dental applications. Like a chameleon can adapt to its environment, Pekkton can be adapted to the different structural and processing requirements needed by dental laboratories.

Unlike PEEK, the Pekkton line offers crystalline as well as amorphous structures, which means a wider range of products can be offered. With the crystalline versions of Pekkton, products with improved mechanical properties, stiffness and chemical resistance can be obtained. Products made out of amorphous Pekkton, on the other hand, reach a higher flexibility and are easier to process. As a result, it is of great interest to dental technicians, who can now produce crown and bridge frameworks more simply.

Due to the ideal viscosity of the material and its large working temperature range, geometrically-complex forms can be produced through casting and compressing the pieces under high temperatures. Thanks to lower shrinking rates during the cool-down process, it is possible to reach higher degrees of accuracy with Pekkton. Also, when using crystalline Pekkton, crowns and bridges with a high chemical and mechanical resistance can be produced. However, the most important mechanical properties can be reached through reinforcing Pekkton with a large amount of fibres.

Healing caps in different sizes.

When producing polyetherketone parts in quantity they usually need to be machined. However, for serial production, injection moulding is an economic alternative. Depending on the required tolerances, crystalline materials may need to be reannealed to relax the internal tensions that accumulate during production. These post-treatments are usually time-consuming and costly. Pekkton, however, has a slow rate of crystallisation, making it is possible to obtain tight tolerances without post-treatments. As it never has to be after-treated, Pekkton can be an interesting solution.

With its greater processing flexibility, the Pekkton line will contribute to the development of successful products that provide both structural and aesthetic satisfaction. ■

Further information
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3.

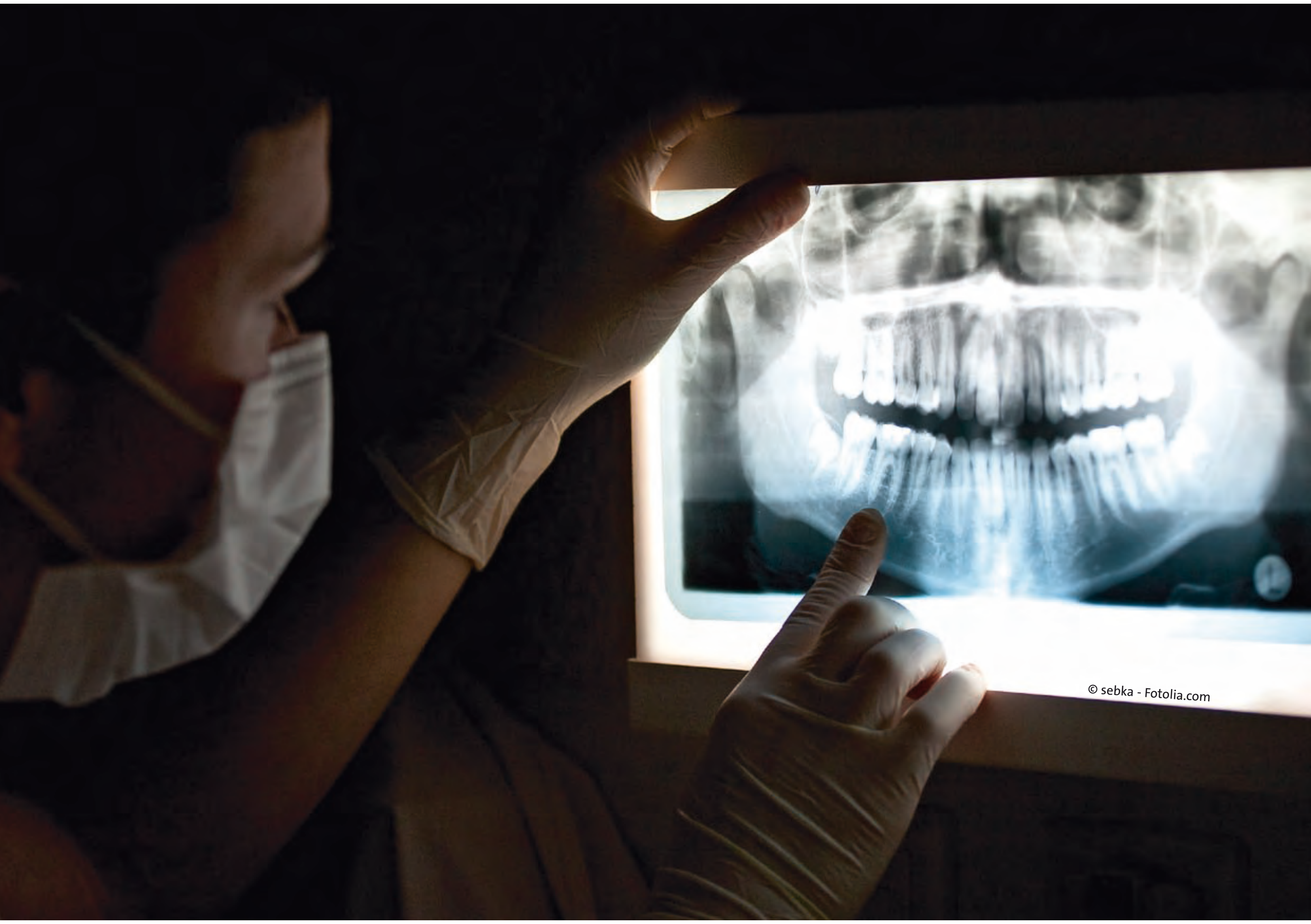
Copponnex T., Blümli M.:
New material approaches in dental technology. meditec, October 2011.

New material approaches in dental technology

Traditional materials used in dentistry, particularly precious metal alloys for crowns and bridges, are increasingly being swamped out of the market. These alloys serve as framework and are subsequently coated and aesthetically veneered with special ceramics. Due to their mechanical characteristics, the well-accepted mouth tolerance, the vast clinical evidence and their simple processing, precious metal alloys have been the material of choice in dentistry for many decades.

However, as a result of some of the material components' very high and volatile market values, like for e.g. gold and platinum, increasingly non-metallic alloys like cobalt-chromium are being pushed. Due to their advantageous market price, cobalt-chromium alloys are nowadays worldwide the most established material for fixed dental prostheses. The downside of precious metal-free alloys is that for crowns and bridges, they are by far not as aesthetic as their precious metal counterpart, usually a dark border is left between the crown and the gingiva.

The need for metal-free solutions in dental prosthetics already exists since quite some time. This trend gained even more importance through the recent amalgam discussions. Initial tests with full ceramic crowns instead of so called bonded metal ceramic crowns as described before, failed because of the



material's high brittleness. However, through computerization and modern manufacturing procedures, it is now possible to profitably process high-performance ceramics in dentistry for customized crowns and bridges.

Due to its very high stiffness, zirconium is applied in three to maximum four-piece bridge frameworks. Hence, the patient receives an aesthetical, biological, high class dental prosthesis. The disadvantage of the material is the considerably higher price compared to bridge frameworks out of cobalt-chromium.

Through technological advancements in the field of high-performance polymers, these materials are now being used wherever the highest demands are made of materials: automotive industry, aerospace, semiconductor technology and medical technology.

Exploring new paths

Outstanding properties also make high-performance polymers ideal for dentistry. Some products for temporary applications are being more and more established in the market: e.g. healing caps for dental implants or implant abutments. For the state-of-the-art manufacturing of crowns and bridges in milling machines, blocks out of high-performance polymers or PEEK are being offered.

A new chapter is now being written with the introduction of materials that have excellent properties for a diversity of applications. Cendres+Métaux is exploring new paths with Pekkton®, a top product among thermoplastics.

PEEK, PEKK – these terms are both numerous and confusing, but these materials all have one thing in common: they belong to the family of poly aryl ether ketones, known as PAEK for short. PAEK are high-performance thermoplastics which, thanks to their chemical structure, have high strength, stiffness and good resistance to hydrolysis and are, thus, suitable for extremely demanding conditions. When thermoplastics are processed, only the form and not their chemical structure is being changed. A crucial advantage when compared to thermoset polymers! The material also does not display any porosity or monomers.

The material PEKK is the latest generation of the PAEK (poly aryl ether ketones) family; it stands at the apex of the quality pyramid of thermoplastics.

Unlike PEEK, PEKK displays both amorphous and crystalline material properties. This makes PEKK particularly interesting. Thanks to its unique mechanical, physical and chemical properties, PEKK lends itself to a broader range of uses than PEEK:

- up to 80% higher compressive strength than PEEK materials,
- wider processing window of parameters than PEEK.

Mimicking nature is the future trend for dental products. Metals and ceramics, even if they are biocompatible, do not fulfill this claim. For instance, bone modulus matching may be important in applications where stress shielding should be minimized. By contrast, polymer-based products are increasingly acknowledged as better alternatives to stiff, rigid dentures in metal or ceramics solutions. Hence the extensive profile of material properties of Pekkton® naturally makes it ideal for different applications in the dental field. The natural high strength and low modulus of Pekkton® products may be increased by the addition of fillers. Stress-demanding applications are then made possible as the properties of human tissues are mimicked.

1

2

1) Removable denture with a framework out of Pekkton® instead of Cobalt-Chromium.

2) With tooth-colored composite veneered dental bridge from below: Pekkton® Bridge (pictured right), compared to a bridge in a cobalt-chromium metal alloy. Pictures: Cendres + Métaux

Stiffness, for instance, can be tailored to human hard tissues through the selection of fillers, their concentration and the processing technique of the resulting composite recipe.

Other important characteristics are:

- high tensile, fatigue and flexural strength,
- ideal dimensional stability,
- excellent wear and abrasion resistance,
- compatibility with all current sterilization methods,
- as well as radiotransparency.

The base material OXPEKK® passed the biocompatibility test over a period of 52 weeks according to ISO 10993 and is licensed by the FDA, the US regulatory authority. The biocompatibility of Pekkton®in accordance with Class USP VI was confirmed by BSL Bioservice Scientific Laboratories GmbH in Munich

Dr. Thierry Copponnex, Director of Development and Markus Blümli, Head of PM New Technologies and Removable Prosthetics Dental Division, Cendres + Métaux

German Summary

Durch den technologischen Fortschritt von Hochleistungspolymeren kann der Einsatz des Materials insbesondere auch in der Medizintechnik laufend erweitert werden. Die herausragenden Eigenschaften prädestinieren Hochleistungspolymere auch für die Dentalmedizin.
Erste Produkte für temporäre Anwendungen beginnen sich im Markt zu etablieren: Zum Beispiel für die Implantologie Einheilkappen und Implantat-Abutments. Für die moderne Herstellung von Kronen und Brücken in Fräsmaschinen werden Blöcke aus Hochleistungskunstoffen oder PEEK angeboten. Mit dessen Einführung wird nun ein neues Kapitel geschrieben. Der Hersteller Cendres+Métaux geht dabei mit Pekkton®, dem Spitzenprodukt der Thermoplaste, neue Wege. Es basiert auf OXPEKK® von OPM, Oxford Performance Materials, Inc., USA. Der deutschsprachige Beitrag ist nachzulesen auf www.meditec-international.com/medi0511cen

4.

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Resin bonding to three types of polyaryletherketones (PAEKs)—Durability and influence of surface conditioning

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ABSTRACT

Objectives. The purpose of this in vitro study was to evaluate the bond strength and durability of adhesive bonding systems to amorphous and crystalline PEKK and fiber-reinforced PEEK using five types of surface conditioning methods.

Methods. One hundred and fifty specimens of each material were conditioned mechanically and chemically, bonded with Multilink Automix to Plexiglas tubes, filled with Multicore Flow, and stored in water at 37 °C for 3, 30 and 150 days. The long-term storage series were thermal cycled between 5 and 55 °C for 10,000 times (30 days) or for 37,500 times (150 days) prior to tensile bond strength test (TBS). Statistical analysis was performed using Kruskal–Wallis and Wilcoxon tests with a Bonferroni–Holm correction for multiple testing ($\alpha = 0.05$).

Results. Fiber-reinforced PEEK exhibited higher bond strengths in all five conditioning groups and at all three storage times than crystalline and amorphous PEKK, which showed lowest TBS. Highest TBS was achieved after conditioning with silica coating and priming (Rocatec Soft, Monobond Plus, Luxatemp Glaze & Bond; TBS up to 23.6 MPa).

Significance. The conditioning method has a significant influence to the bond strength of the bonding to the amorphous and crystalline PEKKs and fiber-reinforced PEEKs.

1. Introduction

Polyaryletherketones (PAEKs) are a group of high-performance semicrystalline thermoplastic resins, which family members differ according to their ratio of keto- and ether-groups (Fig. 1). With a higher ratio and sequence of keto groups, the rigidity of the polymer chain and the glass, as well as melting temperature are increasing [1,2]. Different PAEKs have similar high-quality characteristics such as good dimensional stability at high temperatures (melting temperature is over 300 °C), high chemical and mechanical resistance against wear, and high tensile, fatigue and flexural strengths ([2,3], see Table 1). According to the manufacturer (Cendres+Métaux, Switzerland) they are compatible with reinforcing materials such as glass and carbon fibers and can be sterilized with the current methods like the gamma- and steam-sterilization [2]. Their characteristics make PAEKs highly attractive for industrial usage. Therefore, their field of application extends from food, aircraft and automobile industry to medical products.

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Table 1 – Physical and chemical properties of amorphous and crystalline PEKK and fiber-reinforced PEEK (according to the information provided by the manufacturer and by www.matweb.com).

Physical and mechanical properties	PEKK (amorphous)	PEKK (crystalline)	PEEK (fiber)
Flexural strength (MPa)	140	200	312
Tensile strength (MPa)	89	117	215
Glass temperature (°C)	160	157	143
Softening temperature range or melting temperature (°C)	305–325	364	341

In medicine, PEEK, the best-known PAEK member, mainly serves as implantation material due to its mentioned features and good biocompatibility. It has been proven as an adequate alternative for the long-term proven titanium in orthopedic applications [4–6]. In dentistry, the usage of PEEKs is increasing mainly as temporary implant abutments [4,5,7]. First results are available as well for its use as dental clasps and frameworks for partial removable dental prostheses [8].

Due to its chemical and physical properties, the high-performance thermoplastic PEKK outclasses all the other PAEK materials [9]. The manufacturer (Cendres+Métaux) reports about an up to 80% higher compressive strength of PEKK as compared to the unreinforced PAEK material PEEK. A wider processing window of parameters makes PEKK also especially interesting for the fabrication of crowns and fixed dental prostheses (FDPs). The possibility of producing different rigidity also makes PEKK useful for different applications, e.g. crystalline PEKK for crowns and FDPs, amorphous PEKK for removable prosthesis. However, a clinically adequate bonding to PEKK is a prerequisite for intraoral usage of bonded PEKK restorations.

Up to date, only rare data on bonding to the class of PAEK materials exists. When testing the tensile bond strength (TBS) of differently conditioned PEEK no adequate bonding could be achieved using dental universal composite resin cement in contrast to using an adhesive composite system [10]. Another study [11] showed that the conditioning of PEEK with air-abrasion or silica-coating improved the adhesive properties of PEEK, because the micro-roughness enhances the contact surface with its functional groups between the PEEK and the adhesive. Another recent study [12] tested different primers on PEEK after artificial aging. Only when using a multifunctional methacrylates containing primer (Luxatemp Glaze & Bond), a durable resin bonding was achieved, which therefore was recommended for clinical use. For bonding to PEKK no data could be found in the dental literature.

In view of the limited data available on bonding to PAEK materials, the purpose of the current study was to evaluate different methods for bonding to amorphous and crystalline PEKKs and to fiber-reinforced PEEK. In addition the durability of the achieved bonding should be tested. The null hypothesis was that the bonding method of surface conditioning does not influence the bonding durability and the used methods.

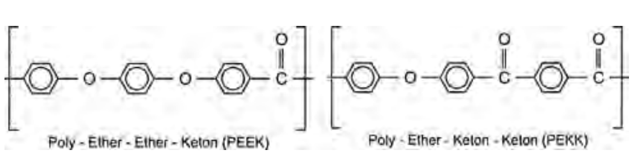

Fig. 1 – Chemical structures of PEEK and PEKK.

2. Materials and methods

In this study, the tensile bond strength and the durability of adhesive bonding of amorphous and crystalline PEKK and fiber-reinforced PEEK discs (150 specimens each) was tested using a luting resin (Multilink Automix, Ivoclar Vivadent AG, Schaan, Liechtenstein). The bonding surfaces of in total 450 discs, with a diameter of 8 mm and a thickness of at least 3 mm each, were polished with rotating silicon carbide paper (SiC Grinding Paper, Grit P600, Bühler GmbH, Düsseldorf, Germany) under water rinsing.

Specimens of each material (amorphous, crystalline, fiber) were divided into the following five groups with different surface conditioning with 30 specimens each.

Pre	For surface cleaning and activation air-abrasion with alumina particles (Rocatec Pre, 3M Espe, Seefeld, Germany) at 0.25 MPa for 15 s was used, then cleaning with compressed air for 15 s. Bonding with Multilink Automix without any adhesion promoter served as negative control group to reveal whether the application of adhesion promoters is effective
PreLu	Air-abrasion with Rocatec Pre at 0.25 MPa for 15 s was used, then cleaning with compressed air for 15 s. Application of the adhesive primer Luxatemp Glaze & Bond (DMG, Hamburg, Germany) for 20 s, light curing (Elipar™ 2500 Halogen Curing Light, 3M ESPE, Seefeld, Germany) for 20 s. Bonding with Multilink Automix. The use of the adhesive primer on the air-abraded surface served as positive control as it has been shown to be effective on PEEK in a previous study [12]
PreLu5	Air-abrasion with Rocatec Pre at 0.25 MPa for 15 s was used, then cleaning with compressed air for 15 s. Application of the adhesive primer Luxatemp Glaze & Bond with storage under a lightproof box for 5 min, light curing for 20 s. Bonding with Multilink Automix. It was assumed that with a longer residence time of the adhesive primer a better penetration into the surface of the substrates might occur resulting in improved bonding

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SoMB	Tribochemical silica-coating through air-abrasion with Rocatec Soft (3M Espe, Seefeld, Germany) at 0.25 MPa for 15 s was used, then cleaning with compressed air for 15 s. Application of the silane containing universal primer Monobond Plus (Ivoclar Vivadent AG, Schaan, Liechtenstein) with a residence time of 5 min. Bonding with Multilink Automix. It was assumed that the combination of silica coating and silane application might be an alternative bonding approach especially in combination with a multifunctional primer such as Monobond Plus which might be effective on both silica-coated and silica-free areas assuming that the silica coverage is not complete
SoMBLu	Tribochemical silica-coating through air-abrasion with Rocatec Soft at 0.25 MPa for 15 s was used, then cleaning with compressed air for 15 s. Application of the silane containing universal primer Monobond Plus with a residence time of 5 min, then application of the adhesive primer Luxatemp Glaze & Bond, light curing for 20 s. Bonding with Multilink Automix. It was assumed that the additional use of the adhesive primer Luxatemp Glaze & Bond might enhance bonding especially in silica-free areas due to better surface penetration

Before chemical conditioning, all discs were cleaned ultrasonically for 3 min in isopropanol (99%, Otto Fischar GmbH & Co. KG, Saarbrücken, Germany) and dried with oil- and water-free compressed air. The materials utilized are listed in Table 2.

2.1. *Tensile bond strength testing*

Plexiglas tubes with an inner diameter of 3.2 mm were filled with the self-curing luting composite Multicore Flow (Ivoclar Vivadent AG, Schaan, Liechtenstein). After 7 min curing time, tubes were bonded to the conditioned amorphous and crystalline PEKK and fiber-reinforced PEEK discs with the dual-curing luting composite Multilink Automix. Before curing, excess material at the bonding margin was removed with foam pellets. A glycerine gel (Liquid strip, Ivoclar Vivadent AG, Schaan, Liechtenstein) was applied to seal the bonding area in order to prevent an oxygenic inhibition layer. The bonded specimens were first light cured with a dental curing light from two opposite sides and then in a curing unit (Dentacolor XS, Heraeus Kulzer GmbH, Wehrheim, Germany) for additional 90 s for definite curing. To ensure a permanent level of contact pressure for all specimens while bonding, this step was completed with an alignment apparatus under a load of 750 g [13,14]. Subgroups of ten specimens each were stored in water at 37 °C for 3, 30 and 150 days. In addition, the longer-term storage subgroups were thermal cycled between 5 and 55 °C for 10,000 times (30 days) or for 37,500 times (150 days).

TBS testing was done using a universal testing machine (Zwick Z010/TN2A, Ulm, Germany) with a crosshead speed of 2 mm/min. A collet held the tube while an alignment jig allowed self-centering of the specimen. The jig was attached to the load cell and crosshead by upper and lower chains, allowing the whole system to be self-aligning and providing a moment-free axial force application. The tensile bond strength (N/mm^2 = MPa) was a calculated using the force in N, which was needed to debond the specimen, and the bonding area in mm^2, which was standardized at 8.04 mm^2.

2.2. *Morphological examination*

To calculate the debonded fractured interfaces of the amorphous and crystalline PEKK and fiber-reinforced PEEK discs for adhesive and cohesive failure modes, the debonded area was inspected with a light stereoscope (Wild Makroskop M420, Heerbrugg, Switzerland) at 25× magnification. After sputtering a gold-alloy conductive layer of about 15 nm, representative samples were examined using a scanning electron microscope (SEM, XL 30 CP, Eindhoven, The Netherlands) with a working distance of 10 mm and an acceleration voltage of 15 keV. To measure the surface roughness representative specimens without any priming were examined in the SEM and analyzed with the 3d-scanning microscope (VK-X100K/X200K, Keyence, Germany).

2.3. *Statistical analysis*

For statistical analysis the Kruskal–Wallis test followed by pair-wise comparison of groups and subgroups with the Wilcoxon test was used. Significance level α was determined at 5% and corrected using the Holm–Bonferroni method.

3. Results

3.1. *Results of the tensile bond strength*

The medians and means of TBS (MPa) of the three different experimental material groups after different surface treatments and different storage conditions are shown in Table 3. The results of the statistical analysis are indicated in Tables 3 and 4. The highest bond strength for all three materials was achieved with the combination of silica coating (Rocatec Soft), and applying a universal primer (Monobond Plus) and a resin primer (Luxatemp Glaze & Bond). The fiber-reinforced material provided the highest TBS of all three materials within all conditioning groups. Although TBS decreased slightly over the storage time of 150 days, these decreases were not statistically significant in most subgroups. However, there were statistically significant differences among the conditioning methods for the three materials.

Table 2 – List of materials and their characteristics.

System	Main composition[a]	Manufacturer	Batch no.
PEKK (amorph)	Polyetherketoneketone, titanium dioxide pigments	Cendres+Métaux, Biel/Bienne, Switzerland	modified PEKK Grade A1 - 09.2009
PEKK (crystalline)	Polyetherketoneketone, titanium dioxide pigments	Cendres+Métaux	Pekkton ivory - 03.2011
PEEK (fiber-reinforced)	Polyaryletherketon, glass fibers, pigments	Cendres+Métaux	PEEK Grade C3 - 02.2009
Multicore flow	Dimethacrylates, inorganic fillers, ytterbium trifluoride, initiators, stabilizers, pigments	Ivoclar Vivadent AG, Schaan, Liechtenstein	N09293 N26726 M43997
Multilink Automix	Hydroxyethyl-, dimethacrylates, inorganic fillers, ytterbium trifluoride, initiators, stabilizers, pigments	Ivoclar Vivadent AG	M55053 N47349
Luxatemp Glaze & Bond	Methacrylates, stabilizer, catalyzer, additives	DMG, Hamburg, Germany	608356
Monobond Plus	Ethanol, silane, silane-, phosphoric-, sulfidemethacrylates	Ivoclar Vivadent AG	M37209
Liquid strip	Glycerine, silicon dioxide, aluminum oxide	Ivoclar Vivadent AG	M32317

[a] According to the manufacturers.

3.2. *Results of bonding failure mode*

The failure mode of the fractured interfaces was predominantly adhesive in all groups (Figs. 2 and 3). The adhesively failed portions were larger in groups with lower bond strengths, while the cohesively failed portions increased groups with higher bond strengths.

The measurement of the surface roughness showed that generally fiber-reinforced PEEK (after air-abrasion with pure alumina about 5.1 μm, after silica coating about 2.6 μm) has a rougher surface than the amorphous (after air-abrasion with pure alumina about 3.4 μm, after silica coating about 2.2 μm) and crystalline PEKK (after air-abrasion with pure alumina about 3.2 μm, after silica coating about 1.8 μm). In Fig. 4 the different surfaces of the three materials are depicted.

4. Discussion

Prior to clinical recommendations, it seems meaningful to conduct in vitro bond strength testing after long-term simulation of oral conditions. Thermal cycling and long-term storage

Table 3 – Results of the bonding strength (MPa).

Material	Groups	Storage time					
		3 d/0 TC		30 d/7,500 TC		150 d/37,500 TC	
		Median	Mean (SD)	Median	Mean (SD)	Median	Mean (SD)
PEKK (amorphous)	Pre	3.1^{A}_{ab}	2.7 (1.9)	5.1^{A}_{a}	6.5 (3.4)	0.0^{A}_{b}	1.1 (2.5)
	PreLu	15.6^{C}_{a}	16.3 (2.3)	13.2^{B}_{ab}	13.6 (1.8)	12.5^{B}_{b}	12.1 (2.1)
	PreLu5	13.7^{D}_{a}	13.9 (1.8)	13.3^{C}_{a}	12.7 (3.7)	12.0^{CD}_{a}	12.1 (2.4)
	SoMB	10.1^{E}_{ab}	9.9 (4.9)	5.2^{D}_{a}	4.8 (3.5)	10.8^{E}_{b}	10.5 (2.6)
	SoMBLu	14.4^{F}_{a}	14.3 (1.3)	12.5^{F}_{a}	12.9 (2.5)	14.3^{G}_{a}	13.7 (1.5)
PEKK (crystalline)	Pre	4.5^{A}_{a}	4.2 (2.4)	1.8^{A}_{a}	2.6 (3.0)	2.2^{A}_{a}	2.8 (2.8)
	PreLu	14.9^{C}_{a}	15.3 (1.7)	11.9^{B}_{a}	12.7 (2.4)	12.1^{B}_{a}	12.9 (2.0)
	PreLu5	15.3^{D}_{a}	15.7 (3.8)	12.6^{C}_{a}	12.9 (2.7)	12.4^{D}_{a}	12.1 (1.6)
	SoMB	16.1^{E}_{a}	15.8 (2.1)	14.4^{E}_{a}	13.6 (5.4)	10.4^{EF}_{a}	10.0 (6.4)
	SoMBLu	18.0^{G}_{a}	17.7 (1.7)	17.2^{FG}_{a}	17.8 (4.8)	16.5^{GH}_{a}	17.7 (4.5)
PEEK (fiber-reinforced)	Pre	15.7^{B}_{a}	14.4 (3.2)	9.2^{A}_{a}	8.0 (3.6)	8.8^{A}_{a}	8.0 (4.8)
	PreLu	18.2^{C}_{a}	18.3 (2.5)	13.3^{B}_{ab}	14.1 (3.4)	13.3^{B}_{b}	13.5 (2.8)
	PreLu5	18.7^{D}_{a}	19.1 (4.0)	15.2^{C}_{a}	14.9 (1.7)	15.6^{C}_{a}	16.0 (1.9)
	SoMB	14.9^{E}_{ab}	15.0 (5.8)	7.5^{DE}_{a}	7.7 (2.9)	14.7^{F}_{b}	15.6 (3.3)
	SoMBLu	23.6^{FG}_{a}	21.8 (8.8)	19.2^{G}_{a}	19.5 (3.7)	21.6^{H}_{a}	21.8 (2.1)

Influence of the three materials within the same conditioning group of the respective aging time on TBS: medians with the same superscript letter within the same column are not statistically different ($p > 0.05$).
Influence of the aging within the same conditioning group of the respective material on TBS: medians with the same subscript letter within the same row are not statistically different ($p > 0.05$).
TC—thermal cycling.

Table 4 – Statistical difference among the five conditioning methods of each material.

Groups	PEKK (amorphous)			PEKK (crystalline)			PEEK (fiber-reinforced)		
	3 d	30 d	150 d	3 d	30 d	150 d	3 d	30 d	150 d
1 vs. 2	*	*	*	*	*	*	n.s.	n.s.	n.s.
1 vs. 3	*	n.s.	*	*	*	*	n.s.	*	*
1 vs. 4	n.s.	n.s.	*	*	*	n.s.	n.s.	n.s.	n.s.
1 vs. 5	*	n.s.	*	*	*	*	n.s.	*	*
2 vs. 3	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
2 vs. 4	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.
2 vs. 5	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
3 vs. 4	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.
3 vs. 5	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	*
4 vs. 5	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	*	*

1—Pre, 2—PreLu, 3—PreLu5, 4—SoMB, 5—SoMBLu; n.s.—not significant, *—significant.

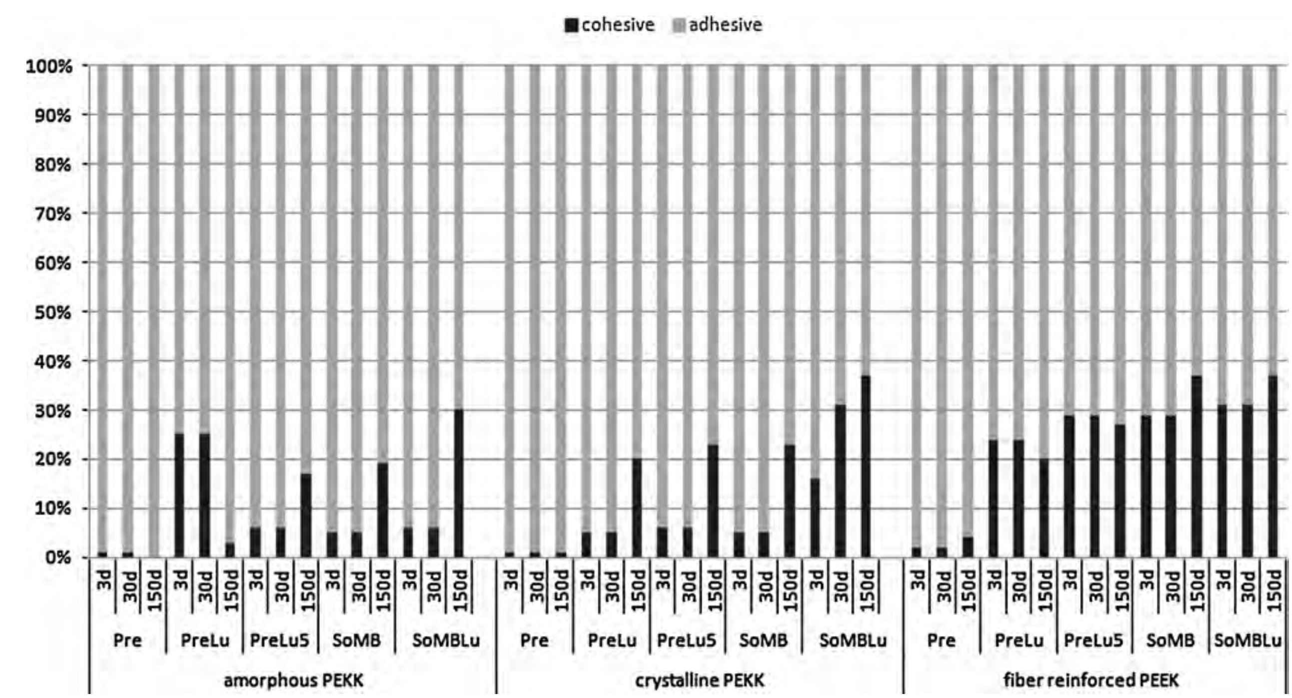

Fig. 2 – Failure mode of bonding groups.

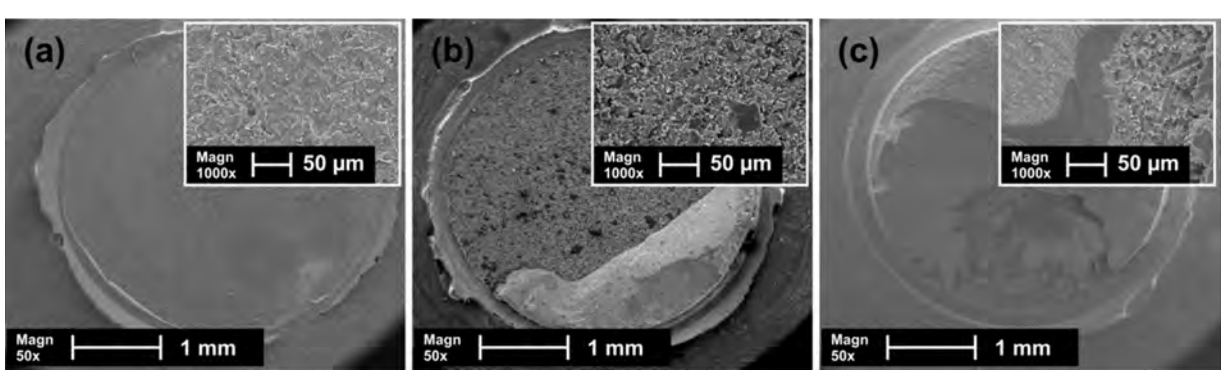

Fig. 3 – Examples for the three different types of failure mode (25× magnification): (a) 100% adhesive failure mode (amorphous PEKK, Pre), (b) mixed failure mode (crystalline PEKK, PreLu5), (c) nearly 100% cohesive failure mode (fiber PEEK, SoMBLu).

Please cite this article in press as: Fuhrmann G, et al. Resin bonding to three types of polyaryletherketones (PAEKs)—Durability and influence of surface conditioning. Dent Mater (2014), http://dx.doi.org/10.1016/j.dental.2013.12.008

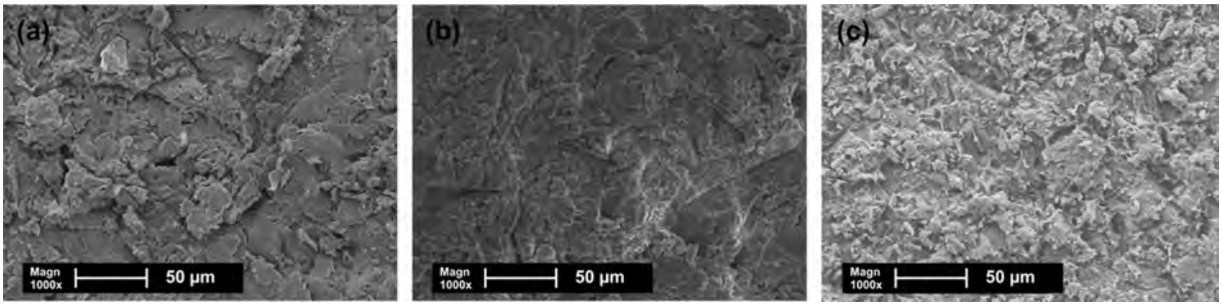

Fig. 4 – Examples of the surface of (a) amorphous PEKK, (b) crystalline PEKK and (c) fiber-reinforced PEEK (1000× magnification).

are the most often used artificial aging methods for testing bonding durability in vitro [14–16] and therefore used in this study.

This is the first study in the field of dentistry which examined bonding to PEKK, as no data for the durability of bonding to PEKK utilizing dental resins are available. The obtained results should be viewed in light of the limitation of this first report on bonding to PEKK materials in dentistry. Dynamic loading of the tested materials and bonding them to different tooth structures might effect the resin bonding and its durability. In addition, different bond test methods might result in varying results, as it is known that the size of bonding area will affect the measured bond strength [17].

Tensile bond strength and its bonding durability were significantly influenced by the conditioning systems and the surface texture of the tested amorphous and crystalline PEKKs and fiber-reinforced PEEKs. Thus, the null hypothesis that there is no influence has to be rejected. Also the failure mode was influenced by the TBS. The higher the TBS the better was the interlocking, so that the cohesive failure mode had a higher ratio. These results are in agreement with previous studies showing that completely cohesive failure modes occurred only when the obtained bond strength exceeded the cohesive strength of the bonding resin [11,18].

When bonding the specimens directly without any priming the group Pre achieved the lowest TBS independent of storage time. Furthermore some specimens debonded prematurely. Only the fiber-reinforced material achieved higher TBS in group Pre than the amorphous and crystalline PEKKs. Due to the embedded fibers of fiber-reinforced PEEK, the rougher surface might have allowed better micromechanical retention to the luting composite (see Fig. 4).

The use of a multifunctional methacrylates containing primer Luxatemp Glaze & Bond was a precondition to obtain high and durable bonding between the composite Multilink Automix and PEEK in a previous study [12] and in the current study. In comparison to the luting material Multilink Automix the adhesive primer Luxatemp Glaze & Bond has a considerably lower viscosity and contains small multifunctional methacrylates which facilitate an infiltration into the rough substrate surfaces achieving durable micromechanical interlocking and possibly chemical bonding. Concerning the residence time of Luxatemp Glaze & Bond, a comparison of group PreLu and PreLu5 (Table 3) showed that a longer residence time of priming did not affect the TBS. Therefore it can be assumed, that the monomer infiltration into the substrate surface is completed within 15 s.

Silica-coating in combination with an universal primer Monobond Plus was equally effective as using air-abrasion with alumina particles and the adhesive primer Luxatemp Glaze & Bond. However, the most effective and durable bonding method for all three polyaryletherketones was the combination of silica-coating and subsequent application of both primers. The silica particle layer obviously enabled a micromechanical interlocking and after silanization with Monobond Plus an additional chemical bonding to the silica particles embedded in the surface [19]. The multifunctional methacrylates containing adhesive primer Luxatemp Glaze & Bond might have penetrated especially into silica-free surface portions providing additional micromechanical interlocking and possibly chemical bonding.

Comparing the three materials, the fiber-reinforced PEEK produced in general the highest TBS for all conditioning methods regardless of the storage time (Table 3). However, statistical analysis revealed that in general TBS of the amorphous and crystalline was not significantly lower than fiber-reinforced PEEK. The reason for high TBS of the reinforced PEEK might be the reinforcing effect of fiber which results in a higher stiffness and strength [20]. In addition, due to its exposed fibers the surface area was rougher in comparison to the amorphous and crystalline type, which benefits a wider extension of the surface area for larger retention area of the bonding system (see Fig. 4). A problem of these exposed fibers could be the penetration of water and bacteria inside the material and the margin fit [21,22] which might affect bonding to the PEEK over long-term. The only material, which showed a durable resin bonding for the whole storage time with every conditioning method, was crystalline PEKK—however on a limited scale.

Achieving durable and leakproof bonding under oral conditions is important for many clinical applications. This study shows first results on bonding to PEKK materials in dentistry and revealed that using a combination of silica-coating and multifunctional methacrylates containing adhesive primer results in considerable bond strengths.

However, additional studies aiming to improve its bonding to PEKK are suggested, especially as first in-vitro studies of PEKK showed promising results regarding its physical characteristics and its prospective use in dentistry [8,23].

Please cite this article in press as: Fuhrmann G, et al. Resin bonding to three types of polyaryletherketones (PAEKs)—Durability and influence of surface conditioning. Dent Mater (2014), http://dx.doi.org/10.1016/j.dental.2013.12.008

5. Conclusion

Highest and most durable bonding to amorphous and crystalline PEKK and fiber-reinforced PEEK was achieved when using the combination of silica coating (Rocatec Soft), universal primer (Monobond Plus) and a resin primer (Luxatemp Glaze & Bond).

Acknowledgments

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5.

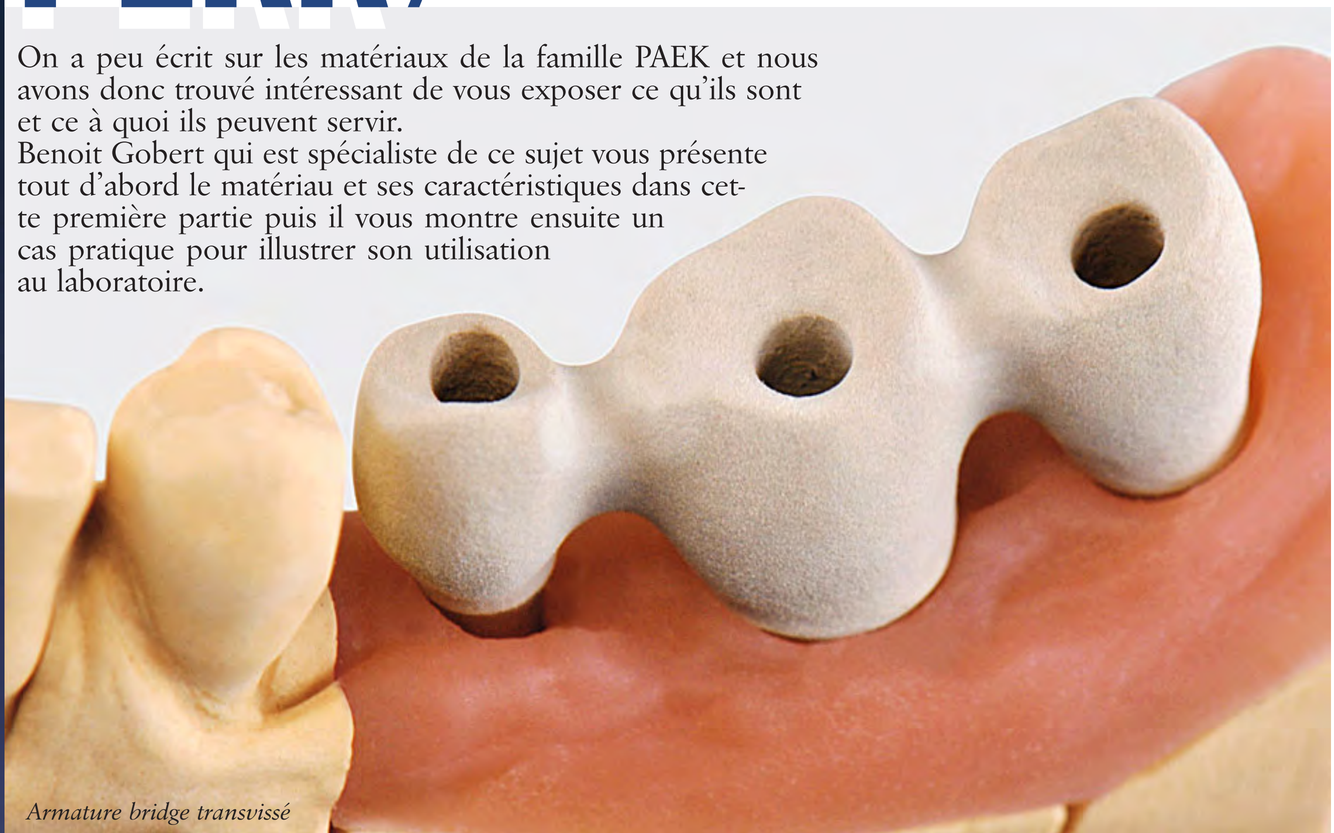
Gobert B.:
C'est quoi le PEKK? Technologie
Dentaire 2014 n° 166.

Par Benoit GOBERT

Prothésiste Dentaire

C'est quoi le PEKK ?

On a peu écrit sur les matériaux de la famille PAEK et nous avons donc trouvé intéressant de vous exposer ce qu'ils sont et ce à quoi ils peuvent servir.
Benoit Gobert qui est spécialiste de ce sujet vous présente tout d'abord le matériau et ses caractéristiques dans cette première partie puis il vous montre ensuite un cas pratique pour illustrer son utilisation au laboratoire.



Armature bridge transvissé

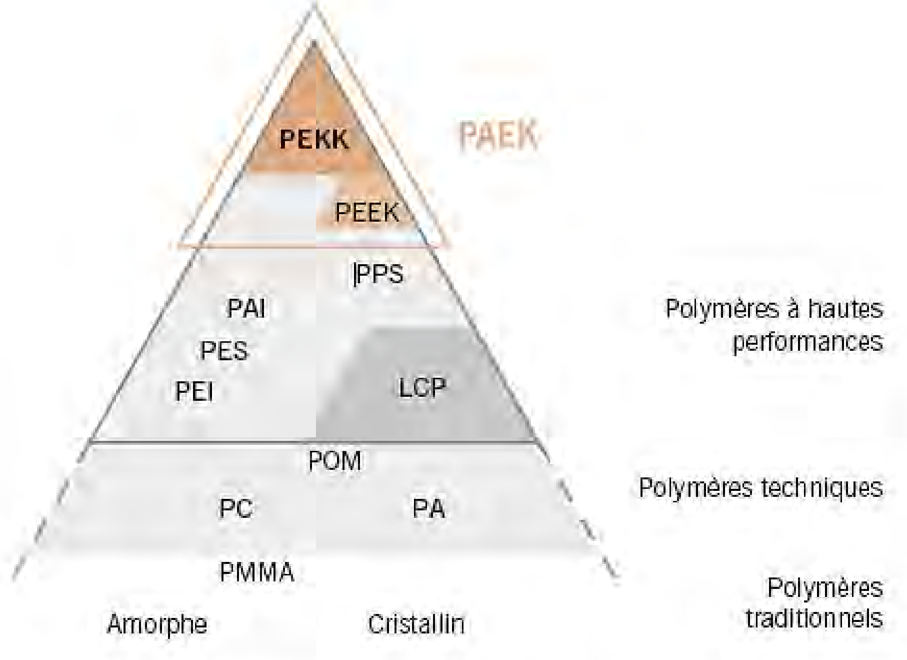
La famille : PAEK

PEEK, PEKK – ces appellations sont aussi fréquentes que déroutantes, mais elles ont un dénominateur commun puisqu'elles appartiennent toutes à la famille des polyaryléthercétones, ou PAEK.

Les PAEK désignent des thermoplastiques à hautes performances présentant une grande résistance, une bonne rigidité ainsi qu'une excellente résistance à l'hydrolyse, le tout sur une vaste plage de températures, les rendant aptes à des applications même sous des contraintes extrêmes.
Lors de la mise en oeuvre de polymères thermoplastiques, la transformation consiste en une mise en forme du matériau sans transformation chimique. Un avantage décisif ! En outre, le matériau ne présente ni porosité ni monomères résiduels.

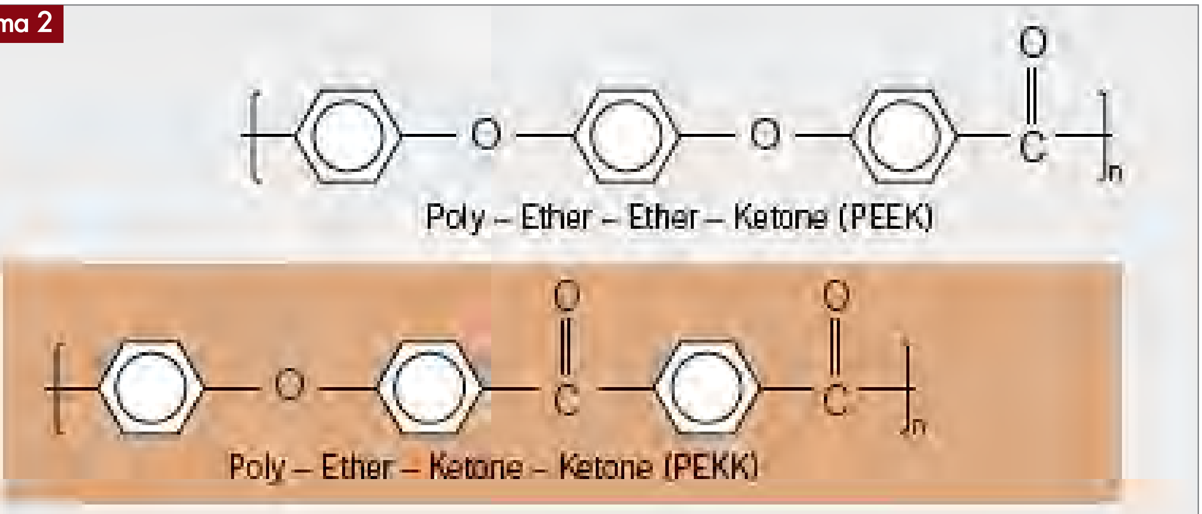
Le matériau PEKK est le summum qualitatif des thermoplastiques.

Schéma 1



Le PEKK se situe au sommet de la famille des PAEK elle-même au sommet de la pyramide qualité des polymères thermoplastiques. Il est disponible sous des structures aussi bien amorphes que cristallines.

Schéma 2



Le plus connu de la famille : PEEK

Au cours des dernières années, le polyétheréthercétone (PEEK) est devenu synonyme de polymère à hautes performances. Il est extrêmement bien accepté dans le domaine médical et s'est imposé dans de nombreux secteurs.

La toute dernière génération, une exclusivité Cendres+Métaux : PEKK

La recherche fondamentale confirme désormais l'avènement du polyéthercétonecétone (PEKK) comme matériau de pointe pour la médecine dentaire (schémas 1 et 2).

Contrairement au PEEK, le PEKK peut se présenter et se mettre en oeuvre sous une structure aussi bien amorphe que cristalline, ce qui le rend particulièrement intéressant selon le type d'application. Grâce à ses propriétés mécaniques, physiques et chimiques uniques en son genre, le PEKK offre ainsi un plus large spectre d'applications que le PEEK avec entre autres :

- une résistance en compression jusqu'à 80 % plus élevée que celle du PEEK.
- une fenêtre opératoire pour la mise en oeuvre plus étendue que ce dernier.

Le matériau idéal pour la médecine générale et dentaire

Imiter la nature est l'un des credos des produits médicaux à venir. Les métaux, même biocompatibles, ne sont pas en mesure d'y satisfaire. Par exemple, l'adaptation au module d'élasticité de l'os peut s'avérer judicieux pour des applications entraînant la réduction au minimum du phénomène de stress shielding (déviation des contraintes).
Les produits à base de polymères s'imposent, a contrario, de plus en plus comme la meilleure alternative aux solutions rigides à base de métaux. Ainsi, Pekkton est naturellement prédestiné, de par son profil de propriétés étendu, aux applications les plus diverses dans le secteur dentaire.
La résistance élevée et le module d'élasticité des produits de la gamme Pekkton peuvent être adaptés par l'ajout de matériaux de renfort. Les applications induisant des charges importantes sont rendues possibles par mimétisme des propriétés tissulaires humaines.
La rigidité par exemple peut être adaptée à celle des tissus durs humains par la sélection de renforts, leur concentration ainsi que la technique choisie pour la mise en oeuvre du matériau final ainsi défini.
Le PEKK peut être mis en oeuvre soit par usinage soit par injection.

Le PEKK ...

... peut être mis en oeuvre par usinage ou par injection.

Les autres propriétés notables sont :

Une résistance à la traction, à la fatigue et à la torsion élevée, une grande stabilité dimensionnelle, une excellente résistance à l'usure et à l'abrasion, une bonne compatibilité avec l'ensemble des procédés de stérilisation traditionnels, ainsi qu'une bonne radio-opacité modulable.

Pekkton ne doit pas être appréhendé comme un simple matériau mais comme une solution systémique.
Le PEKK peut se combiner à d'autres composants de renfort comme le verre ou les fibres de carbone, ce qui contribue encore à accroître ses propriétés mécaniques.
Pekkton peut être employé en médecine dentaire pour réaliser :

- des couronnes,
- des bridges, des squelettés,
- des gaines,
- des piliers
- et des pièces pour implants.

Les matériaux de la famille Pekkton peuvent être utilisés aussi bien pour des solutions provisoires que définitives. Ils peuvent être mis en oeuvre facilement et en toute fiabilité au moyen des procédés traditionnels. Les produits finis ou semi-finis sont le plus souvent obtenus par injection, par pression ou par fraisage. Amorphe ou cristallin : différents paramètres de traitement.

Sous leur forme amorphe, les macromolécules de Pekkton sont désordonnées, à l'instar d'une pelote de fils emmêlés. Le polymère amorphe est moins rigide, il dispose d'une certaine « élasticité ».

Sous leur forme cristalline, les macromolécules de Pekkton se composent de chaînes carbonées partiellement ordonnées. Elles sont liées par des liaisons physiques de type faible. Ces forces de liaison sont plus efficaces sur les zones ordonnées des macromolécules. Les matériaux cristallins sont chimiquement plus résistants et plus rigides.

La différence est également visible lors de la mise en oeuvre, par le comportement à l'état liquide et au refroidissement : on constate un retrait nettement moins significatif pour le matériau amorphe que dans le cas de la forme cristalline.

Le matériau de base OXPEKK (Pekk de grade médical) a passé avec succès les tests de biocompatibilité sur une période de 52 semaines, conformément à la norme ISO 10993, et est homologué par les autorités sanitaires américaines, FDA. La biocompatibilité de Pekkton selon la classe USP VI a été confirmée par BSL Bioservice Scientific Laboratories GmbH, à Munich.

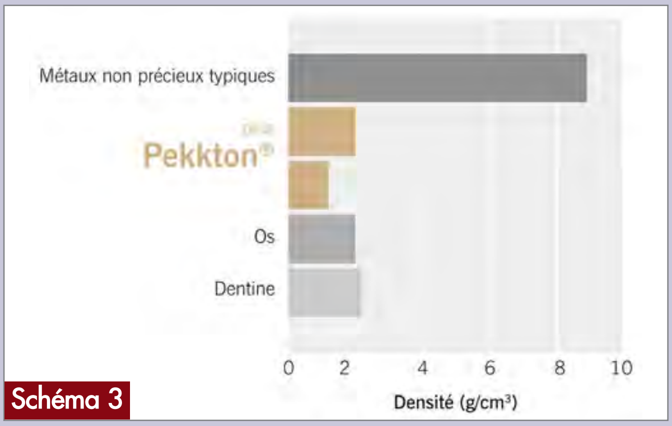


Schéma 3

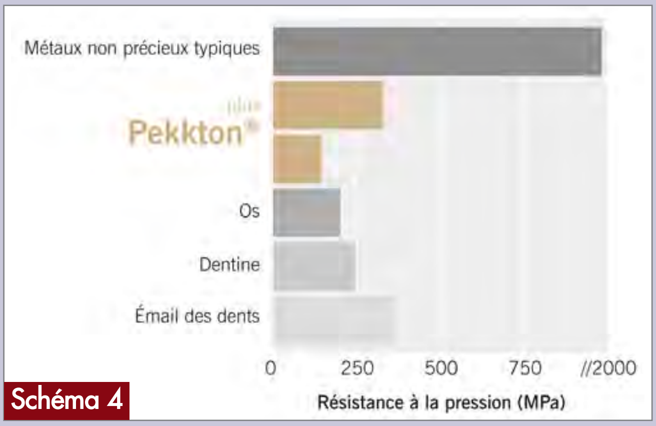
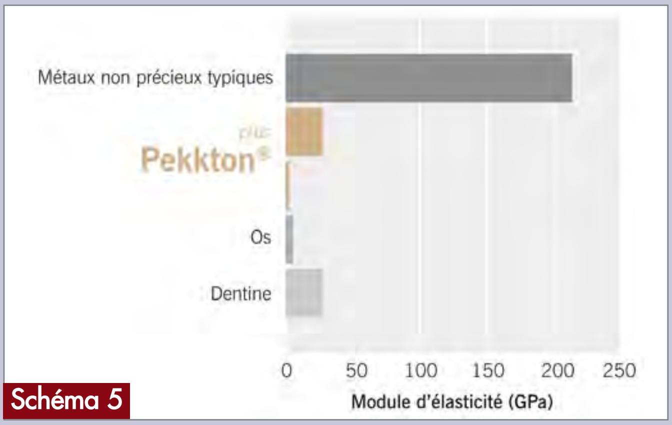


Schéma 4



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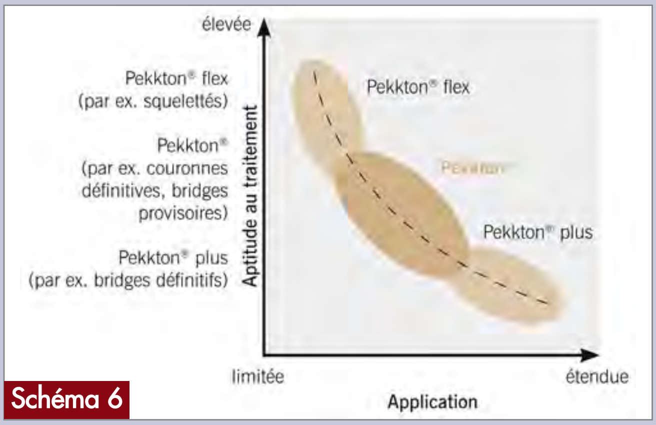


Schéma 6

Caractéristiques physiques des Pekk :

Densité (g/cm³) : (schéma 3)
La densité du Pekkton plus correspond à celle de l'os et de la dentine chez l'homme.
Résistance à la pression (MPa) : (schéma 4)
Le Pekkton est comparable à la dentine en termes de résistance à la pression et présente un comportement moins invasif que les métaux non précieux.

Module d'élasticité : (schéma 5)
La rigidité de Pekkton plus est quasiment identique à celle de la dentine.
Application : (schéma 6)
Aptitude élevée à la mise en oeuvre : bonne fluidité, large spectre de paramètres de mise en oeuvre.
Aptitude limitée à la mise en oeuvre : fluidité restreinte, spectre de paramètres de mise en oeuvre étroit.

Quelques exemples de réalisations en PEKK :


Bridge transvissé stratifié au composite.


Usinage d'une armature de bridge.


Armatures de bridge.


Autres armatures sur modèle.

6.

Gobert B.:
Faux moignon anatomique en Pekkton®. Technologie Dentaire 2014 n° 166.

CENDRES+ MÉTAUX

“ La biocompatibilité du Pekkton Ivory apporte des avantages déterminants…”

Par Benoit GOBERT
Prothésiste Dentaire

Mise en oeuvre du Pekk dans un cas pratique :

Faux moignon anatomique en Pekkton

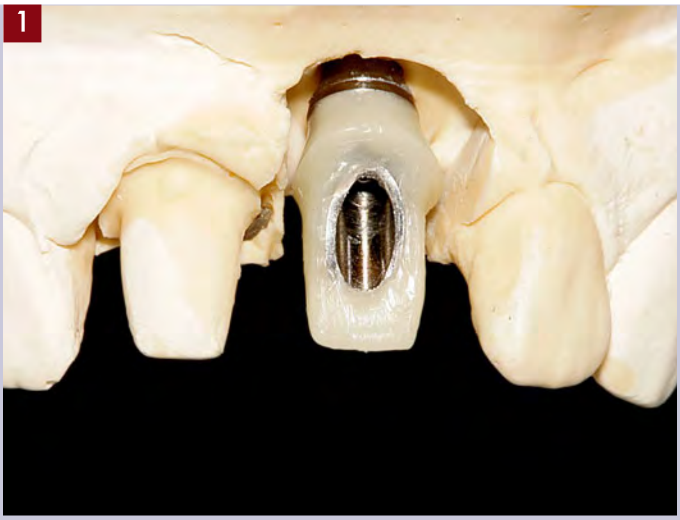
Description du cas clinique

Contexte et objectifs du traitement :

La biocompatibilité du Pekkton Ivory n'est aujourd'hui plus à démontrer. Elle apporte des avantages déterminants lors de la réalisation de FMIP (Faux Moignons Implantaires en Pekkton). Sa haute biocompatibilité permet une cicatrisation rapide, un maintien des papilles et une réaction inflammatoire minime de la gencive environnante.
De par sa composition lePekkton joue un rôle d'amortisseur en s'intercalant entre l'implant et la couronne céramique.
Cette notion en implantologie existe depuis longtemps, car la société Friadent avec son implant cylindrique IMZ possédait un IME (Intra Mobile Elément), une pièce en POM (polyoxyméthylène), avec ou sans renforcement d'une bague en titane.
Le but de cette dernière était de reproduire le rôle élastique du ligament alvéolodentaire. Un vieux concept qui refait donc surface avec cette nouvelle classe de matériaux.

Anamnèse du patient :

Le patient de ce cas clinique a reçu un choc sur les deux centrales qui a fracturé la racine de la 21, ce qui a nécessité après extraction et cicatrisation la pose d'un implant Straumann synocta (Régular Neck). La fracture horizontale profonde sur la 11 implique la réalisation d'une couronne céramo-céramique type e.max.



1 Modelage anatomique en cire sur un pilier en titane préalablement traité en utilisant une fausse gencive.

2 Sur la gauche, positionnement du faux moignon implantaire pour l'injection de Pekk (à gauche) et à droite profil distal du FMIP (Faux Moignon Implantaire en Pekkton ivory) après polissage.

3 Réalisation de provisoire en résine au moyen de facettes préfabriquées.

4 Vue clinique du FMIP deux minutes après son positionnement. Le faible blanchiment de la gencive valide l'utilisation d'une fausse gencive au laboratoire et de son travail de profilage.

Etapes de réalisation

Le maître modèle est réalisé avec une fausse gencive amovible afin de pouvoir travailler le profil d'émergence du futur FMIP.
Un modelage anatomique en cire est construit sur un pilier en titane, utilisé pour la réalisation de provisoires de longue durée. Ce dernier a été préalablement traité par sablage 110 microns à 4 bar pour augmenter l'adhésion du Pekkton lors de sa pressée à basse fusion (photo 1).
Le positionnement des éléments à presser se fait avec le même protocole que pour la céramique pressée traditionnelle. A cette étape de fabrication, il est impératif de suivre à la lettre le mode d'emploi du fabricant. Le profil de chauffe du cylindre, son refroidissement, et l'injection sont incontournables. Le four de pressée doit démarrer sa chauffe à très basse température, environ 390 °C. Après sablage aux billes de verre, l'état de surface du FMIP au niveau gingival doit être poli en utilisant une vitesse de rotation ne dépassant pas les 7500 trs/min. La partie visible du moignon peut se surfacer à la fraise diamantée gros grains (photo 2).
Les deux couronnes provisoires sont réalisées en utilisant des facettes provisoires en composite de Merz dental (photo 3). Attention au pouvoir mimétique du composite, il peut être supérieur à celui de la céramique !!! On ne pourrait retrouver cette valeur lors de la réalisation des céramo-céramiques.
Cette vue clinique du FMIP a été prise 2 minutes après son positionnement. On notera le faible blanchiment de la gencive. Il est dû à l'utilisation de la fausse gencive et à son profil d'émergence (photo 4).

Les provisoires sont mises en place. L'empreinte définitive sera faite un mois plus tard afin de réaliser deux céramo-céramiques du type e.max (photo 5).

5

Mise en place des provisoires.

6

Vue latérale des couronnes définitives céramo-céramiques 11 et 21.

7

Maturation gingivale après 3 mois sous provisoires, la finesse de la papille centrale est une réponse positive au protocole employé.

8

Collage des deux éléments.

Les e.max sont réalisées avec une infrastructure HO1, puis stratifiées de façon classique. Cette vue latérale des couronnes définitives montre le travail d'état de surface des 11 et 21 (photo 6).
Après 3 mois de maturation gingivale, les céramiques définitives vont pouvoir être collées. On notera la finesse de la papille centrale qui pendant ce laps de temps est remontée en direction du bord libre. Voilà le premier constat positif : le protocole ainsi que le matériau employé, à savoir le Pekkton, donnent une réaction tissulaire positive (photo 7).
Après quelques minutes d'essayage des couronnes, la gencive trouve un aspect encore plus rose clair. La céramique a une réaction inflammatoire gingivale beaucoup plus faible que la résine, même polie miroir, il restera les microporosités qui seront les nids inflammatoires pour la gencive (photo 8).

Cette dernière photo a été prise deux mois après le collage définitif. Le niveau gingival est maintenu, il est très positif et ne comporte aucune réaction inflammatoire (photo 9).

Trucs et astuces de l'auteur :

Afin d'augmenter l'esthétique de la reconstruction du FMIP, il est préférable de recouvrir complètement le cylindre en titane donnant accès à la vis par du Pekkton ivory, de combler au moyen d'un peu de coton, de gutta blanche ou de composite blanc opaque, le trou d'accès de la vis afin d'éviter la réflexion grise du titane lors des différents essayages et du scellement final. Le pilier en Pekkton ivory avant scellement doit être nettoyé, micro-sablé ou activé au moyen d'une fraise diamantée grain moyen puis bondé selon le mode d'emploi du fabricant de composite de collage.

Un résultat esthétique très satisfaisant.

Conclusion

L'utilisation du Pekkton ivory est un apport incontestable dans la bio-intégration gingivale de nos reconstructions. Le maintien des papilles à des fins esthétiques est capital pour la beauté mais aussi la pérennité des réalisations implanto-portées. La forme homothétique du FMIP (Faux Moignon Implantaire en Pekkton ivory) ainsi que sa compression en mésio-distal contrôlée est également déterminante pour le soutien des tissus mous environnants.

Benoit Gobert
Le Lignon Suisse
www.benoitgobert.ch

Remerciements : Tous mes remerciements vont à la société Cendres+Métaux de Bienne et plus particulièrement, M. Walter Wermuth, M. Copponnex, M. Markus Blümli, Mme Sandra Haldi et M. Beat Dorfler, pour leur soutien technique durant cette dernière année.

Deux mois après la pose, la réaction tissulaire est très positive et ne comporte aucune réaction inflammatoire.

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Keilig L., Katzenbach A., Weber A.,
Stark H., Bourauel C.:
Biomechanische Untersuchung
eines Hochleistungspolymers
für den Ersatz in der dentalen
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tagung der Deutschen Gesellschaft
für Biomechanik (DGfB) 2013
in Ulm.

098 -

Zahn- und Kieferbiomechanik

Biomechanische Untersuchung eines Hochleistungspolymers für den Einsatz in der dentalen Prothetik

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Fragestellung

Für die Überkronung von Zähnen in der zahnärztlichen Prothetik steht eine große Zahl verschiedener Materialien mit unterschiedlichen mechanischen und chemischen Eigenschaften zur Verfügung. Insbesondere das mechanische Verhalten dieser Materialien sowie des Verbundes von Zahn, Kronenmaterial und Verblendung bei den ablaufenden mechanischen Belastungen ist dabei von großem Interesse. In der vorgestellten Untersuchung sollte ein neu eingeführter Werkstoff aus einem Hochleistungspolymer (Pekkton, Cendres+Métaux, Schweiz) mit werkstoffwissenschaftlichen und numerischen Methoden untersucht werden.

Methoden

Es wurden sowohl eine Molarenkrone als auch eine dreigliedrige Brücke (Prämolar bis zweiter Molar) untersucht. Dies entspricht den zugelassenen Anwendungen des untersuchten Materials. Von beiden Probekörpern wurde eine Reihe identischer Kopien hergestellt. Für die Verblendung wurde das vom Hersteller empfohlene Material (SR Nexco, Ivoclar Vivadent) verwendet. Eine Prüfung auf humanen Zähnen als Zahnstumpf war nicht möglich, da so keine ausreichende Zahl identischer Prüfkörper hergestellt werden konnte. Stattdessen wurden sowohl Stümpfe aus Stahl wie auch aus PMMA, jeweils mit idealisierten Zahnwurzeln, verwendet. Zur werkstoffwissenschaftlichen Untersuchung wurde eine Dauerlastuntersuchung durchgeführt. Die Belastung erfolgte dabei mit einem kugelförmigen Belastungsstempel (Durchmesser 5 mm) mit Kraftangriff im Kronenmittelpunkt unter einem um 30° zur Zahnachse geneigten Winkel. An je drei Probekörpern wurde zuerst die statische Bruchlast bestimmt. Mit dieser Bruchlast wurde der Startwert für die Dauerlastprüfung ermittelt. Die Belastung erfolgte im Druckschwellbereich mit einem sinusförmigen Lastverlauf in flüssigem Medium bei 2 Hz und über $2x10^6$ Lastzyklen. Als Versagenskriterium wurde ein Riss in der Verblendung oder ein Bruch der Probe definiert. Zur numerischen Untersuchung mit der Finite-Elemente(FE)-Methode wurde die Oberfläche des Stumpfes sowie der Krone mit und ohne Verblendung optisch gescannt und basierend darauf ein 3D-Modell der prothetischen Versorgung erstellt. Es wurde die statische Belastung bei Verwendung verschiedener Stumpfmaterialien (Stahl, PMMA, humaner Zahn) und Verblendungsmarterialien simuliert.

Ergebnisse

In den durchgeführten Dauerlastuntersuchungen ergab sich für die verblendete Pekkton-Krone eine Dauerfestigkeit von über 600 N. Erst bei zyklischer Belastung oberhalb von 900 N traten im Testverlauf bei allen Proben Risse in der Verblendung beziehungsweise im Kronenmaterial auf. Bei den FE-Simulationen zeigten sich bei Verwendung eines Stahlstumpfes sehr hohe Spannungsspitzen am Übergang zwischen Stumpf und Krone. Bei den Simulationen mit den Materialparametern von Zahn beziehungsweise PMMA konnten diese nicht beobachtet werden.

Schlussfolgerungen

Sowohl im Dauerlastversuch als auch in den numerischen Simulationen hat sich das untersuchte Material als aus biomechanischer Sicht uneingeschränkt geeignet für die Verwendung als Provisorium erwiesen. Die Wahl des Stumpfmaterials beeinflusst teilweise stark die gewonnenen Ergebnisse. Dennoch bietet das ermittelte mechanische Verhalten der untersuchten prothetischen Versorgungen bei den typischen intraoralen Lasten einen ausreichenden Spielraum.

Wir danken der Fa. Cendres+Métaux für die Bereitstellung der Materialien sowie der Materialdaten des Polymers.

8.

Pham V.T.:
Pekkton® Nouveau polymere hautes performances. Technologie Dentaire 2014 n° 169.

CENDRES+ MÉTAUX


" Le matériau dentaire le plus proche des caractéristiques biologiques du corps humain… "

Par Van-Thanh PHAM

Prothésiste Conseil auprès de Cendres+Métaux France

Pekkton

Nouveau Polymère Hautes Performances… Esthétique et souplesse pour vos restaurations implantaires

Lancé lors du salon de l'IDS 2013, Pekkton, le matériau polymère hautes performances de la famille des PAEK, mis au point par Cendres+Métaux, arrive sur le marché français.

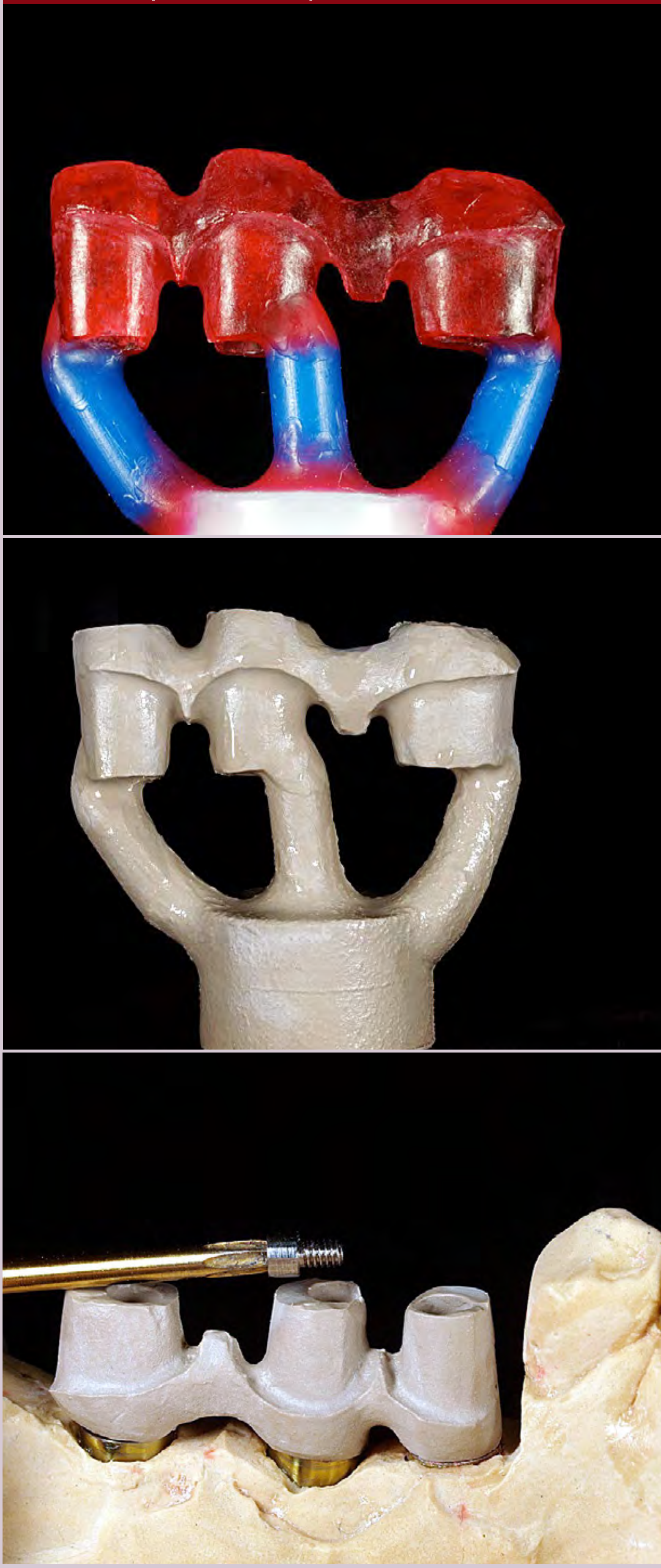
Cette famille de polymères, utilisée en médecine traditionnelle notamment pour des reconstitutions osseuses et devant servir à la confection d'armatures de prothèses dentaires, se distingue par son fort pouvoir d'amortissement et son caractère hautement biocompatible. De plus, sa couleur blanc cassé lui procure des atouts esthétiques majeurs.

En termes de propriétés mécaniques, Pekkton est à ce jour le matériau dentaire le plus proche des caractéristiques biologiques du corps humain. Sa densité (inférieure à 2g/cm3), sa résistance à la pression (entre 200 et 300 MPa) et son module d'élasticité sont comparables à ceux de la dentine, de l'émail ou de l'os.

Cette souplesse relative et cette légèreté sont tout particulièrement appréciables du point de vue clinique pour les restaurations implantaires. Dans ce domaine, on peut dire qu'on n'a rien trouvé de mieux depuis l'or !

1 Molaire monobloc en Pekkton Ivory (Laboratoire Cristou)

2 Armature implantaire télescope (Laboratoire Cristou)



Quelques exemples de réalisations :

Un matériau polyvalent

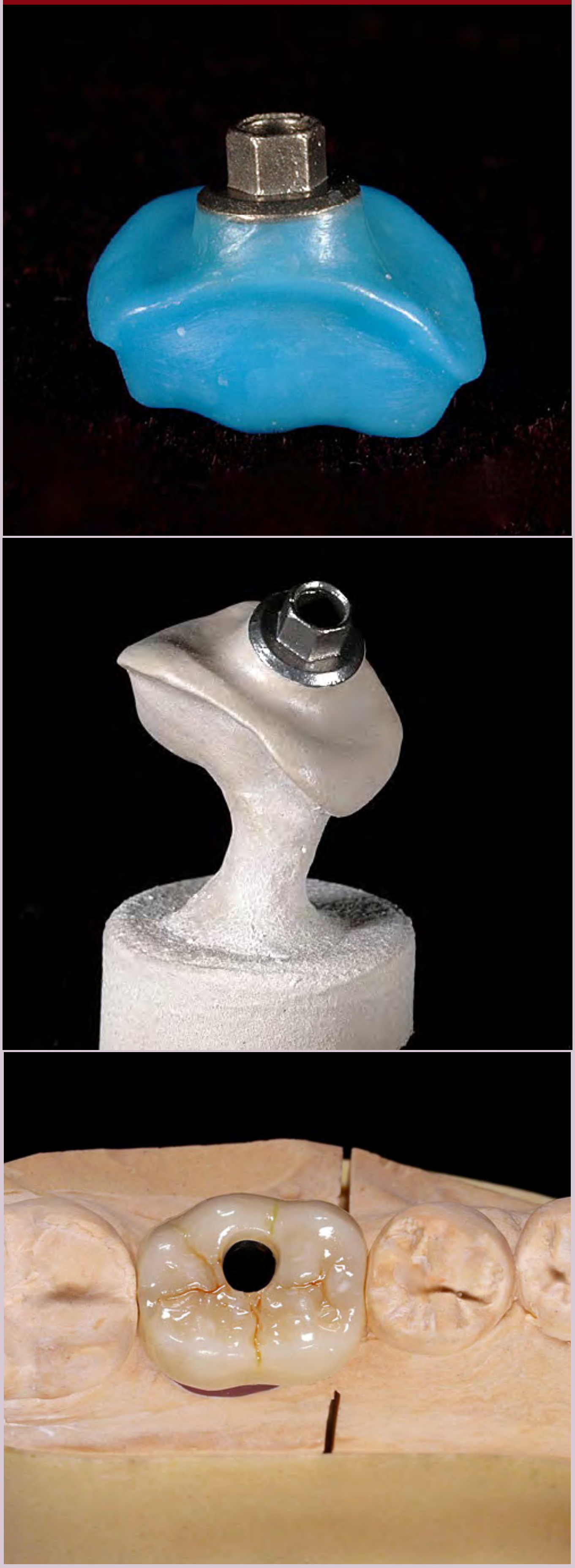
« Qui peut le plus, peut le moins » ! Si l'utilisation de Pekkton prend tout son sens en implantologie, il a aussi été conçu pour devenir l'atout des prothésistes pour les travaux du quotidien qui restent les plus nombreux : couronnes et bridges sur dents naturelles, inlays-core avec ou sans clavette, onlays et même couronnes monolithiques postérieures. En effet, Pekkton peut se travailler de deux façons : par la technique de la pressée tout comme la céramique, ou par usinage dès l'été 2014.

La version pressée de Pekkton est la plus souple d'utilisation et la plus universelle car elle laisse au prothésiste un grand choix d'applications possibles.

La pressée peut se faire dans un four de même type que le Dekema Press-i-dent ou bien à l'aide des appareils développés dans ce sens par Cendres+Métaux sur la base d'un cahier des charges défini entre autres avec le concours du Laboratoire Cristou, spécialiste en la matière.

3 Inlay-core à clavette (Laboratoire Cristou)

4 Couronne transvissée (Laboratoire Cristou)



5 PEKKTherm four de stabilisation

6 PEKKPress pour la pressée

7 Bridge sur implants coiffé de Full Zircone - BDT & Dr. Richard Anderson, Leeds, RU

Une manipulation simple et rapide

Avec l'utilisation combinée d'un four de préchauffe classique de PEKKtherm (photo 5) pour la stabilisation à température et de PEKKPress (photo 6) pour la pressée vous pouvez commencer à utiliser Pekkton du jour au lendemain. Vos clients dentistes apprécieront sans doute ce nouveau matériau qui deviendra une arme majeure pour tous les laboratoires qui cherchent à se différencier de leurs confrères.

Ainsi, avec un investissement de base réduit (moins de 3000 euros), chaque laboratoire peut se lancer progressivement en commençant par exemple à remplacer les couronnes coulées en alliage non-précieux par des couronnes monobloc pressées en Pekkton, avant de s'attaquer à des travaux de plus grande envergure. Mais avec un point de fusion de seulement 360°C, il ne faut pas perdre de vue que Pekkton est maléable à souhait et qu'il saura s'adapter facilement à de nombreux types de travaux.

Van-Thanh PHAM

Prothésiste Dentaire conseil auprès de Cendres+Métaux France

Renseignements :

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www.cmsa.ch/dental

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9.

Tannous F., Steiner M., Shahin R., Kern M.:
Retentive forces and fatigue resistance of thermoplastic resin clasps. Dental Materials 2012 Mar;28(3):273-8.

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Retentive forces and fatigue resistance of thermoplastic resin clasps

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ABSTRACT

Objectives. The objective of this study was to evaluate the retentive force of clasps made from three thermoplastic resins and cobalt–chromium (CoCr) alloy by the insertion/removal test simulating 10 years use.

Methods. On standardized premolar metal crowns 112 clasps were fabricated, including 16 CoCr (1.0 mm thick) clasps and 32 clasps (1.0 or 1.5 mm thick) from each of the following thermoplastic resins: polyetheretherketon (PEEK), polyetherketonketon (PEKK) and polyoxymethylene (POM). Specimens were divided in subgroups with clasp undercuts of 0.25 mm and 0.5 mm, respectively. Each clasp assembly was subjected to an insertion/removal test on its abutment crown for 15,000 cycles. To analyze the retention over the course of insertion/removal test, retention was measured every 1500 cycles. Data were statistically analyzed using 3-way ANOVA ($\alpha = 0.05$).

Results. Resin clasps with 1.5 mm thickness showed higher retention (4.9–9.1 N) than clasps with 1.0 mm thickness (1.2–3.1 N; $P \leq 0.001$). Resin clasps of both dimensions had significantly lower retentive force than CoCr clasps (11.3–16.3 N; $P \leq 0.001$). Clasps with 0.25 mm undercut showed significantly less retention than clasps with 0.50 mm ($P \leq 0.001$). All clasps exhibited an increase in retentive force during the first period of cycling followed by continuous decrease till the end of the cycling but it was still significantly not different compared to the initial retentive force ($P = 0.970$).

Significance. Thermoplastic resin clasps maintained retention over 15,000 joining and separating cycles with lower retention than CoCr clasps. However, the retention of adequately designed resin clasps might be sufficient for clinical use.

1. Introduction

The emphasis on physical appearance in contemporary society has increased the demand for esthetic dental restorations. Although the success of implant dentistry has expanded the scope of esthetic fixed prostheses, there are still many patients who for health, anatomic, psychological, or financial reasons are not candidates for implants [1]. These patients have the option of receiving partial removable dental prostheses (PRDPs) to replace missing teeth.

A major esthetical problem with PRDPs is the display of the clasp assemblies. Many methods have been used to overcome the esthetic problem such as etching the clasp arm and coat it with a layer of tooth-color resin [2], using lingual retention design [3], or proximal undercuts (also known as rotational path insertion) [4–6].

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Table 1 – Materials used for clasp fabrication.

Brand name	Composition	Manufacturer	Batch number
Acetal Dental	Polyoxymethylene (POM)	Dental Srl, San Marino, Italy	01065
Bio XS	Polyetheretherketon (PEEK)	Bredent, Senden, Germany	540XS016901
PEKKtone A	Polyetherketonketon (PEKK)	Cendres Metaux, Bienne, Switzerland	X1074M
Wironit	Co 64%; Cr 28.6%; Mo 5% (CoCr)	Bego, Bremen, Germany	12769

Direct retainers fabricated in a tooth-colored material and made from thermoplastic resin have been used to improve the appearance of metal clasp assemblies and are promoted for superior esthetics [7–9]. However, little information on the long-term performance of such clasps regarding retention is available in the literature.

Polyetheretherketon (PEEK) and polyetherketonketon (PEKK) are polymers from the group polyaryletherketone (PAEK) which is a relatively new family of high-temperature thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups [10]. In medicine PAEK has been demonstrated to be excellent substitute for titanium in orthopedic applications [10,11], and it has been used in dentistry as provisional implant abutment [12].

Polyoxymethylene (POM) also known as acetal resin, an injection-molded resin has been introduced as an alternative to conventional PMMA. POM is formed by the polymerization of formaldehyde. The homopolymer, polyoxymethylene is a chain of alternating methyl groups linked by an oxygen molecule. It has a relatively high proportional limit with little viscous flow enabling it to behave elastically over a great enough range to be used as a material for clasp construction [7].

Various metallic materials have been used to fabricate the clasps of PRDPs and the physical properties of these materials have been examined [13–23]. The most common alloys used for clasps are cobalt–chromium (CoCr) alloys [21]. There have been studies that investigated the retention properties of CoCr alloys using repeated insertion/removal tests. Rodrigues et al. indicated an increase in retentive force during the simulating test [16], while retention decrease was reported by both Bridgeman et al. [20] and Kim et al. [24].

Retentive clasp arms must be flexible and should retain the PRDP satisfactorily. In addition, clasps should not unduly stress abutment teeth or be permanently distorted during service [25]. Previous studies indicated that PRDP clasps made of more elastic materials demonstrated a higher resistance to retention loss [24,25].

Due to the low modulus of elasticity (2–4 GPa) (Table 3) [8,10], thermoplastic resin has superior flexibility compared to the conventional CoCr alloys. Because of the reduced possibility of traumatic overloading, clasps made from thermoplastic resin can be designed to engage deeper undercuts on abutment teeth.

There are few studies that examined flexural properties of POM to determine the appropriate design for PRDP clasp [7,8]. Arda and Arikan found that POM clasps are resistant to deformation and may offer a clinical advantage over conventional metal clasps [9]. However, to our best knowledge there are no studies evaluating the use of PEEK and PEKK as clasp materials.

Therefore, this in vitro study investigated the retentive force of different thermoplastic resin clasps during repetitive placement and removal on abutment teeth with two different thicknesses and two amounts of undercut. Conventional CoCr clasps were included as control group. The null hypothesis was that there would be no difference in the retentive force between resin clasps and cast CoCr alloy clasps.

2. Materials and methods

Three thermoplastic resins (POM, PEEK and PEKK) and a conventional CoCr alloy were evaluated in this study.

All used materials are presented in Table 1.

2.1. *Abutment fabrication*

An artificial maxillary first premolar (KaVo, Biberach, Germany) was embedded in auto-polymerizing acrylic resin (Technovit 4000; Heraeus-Kulzer, Wehrheim, Germany) using custom-made copper holders with a diameter of 15 mm.

The maxillary first premolar was prepared for a surveyed complete metal crown. The prepared premolar was dublicated twice using a polyether impression material (Impregum Penta H and L; 3M Espe, Seefeld, Germany). The impressions were poured in Type IV stone (GC Fujirock EP; GC, Leuven, Belgium), and a complete crown was waxed on each preparation (Crowax; Renfert GmbH, Hilzingen, Germany).

The waxed crowns were surveyed to provide an undercut of 0.25 mm on one crown and 0.50 mm on the other. Occlusal rests, 2.5 mm long, 2.5 mm wide, and 2 mm deep, were placed mesially. Mesial and lingual guide planes, two thirds the length of the crown, were prepared with a surveyor blade to standardize the path of insertion. The waxed 2 crowns were duplicated with silicon material (Speedy Wax Transpaduplisil 101; Zahntechnik Norbert Wichnalek, Augsburg, Germany), and then 16 crowns with 0.25 mm undercut and 16 with 0.50 mm undercut were made by inserting heated liquid wax (Speedy Wax Injektionswachs 70; Zahntechnik Norbert Wichnalek) into the silicone mold. Then the crowns were cast in CoCr alloy (Wironit 99; Bego, Bremen, Germany).

After fitting and finishing, the crowns were cemented in place on the abutments with zinc phosphate cement (Hoffmann quick setting, Hoffmann, Berlin, Germany). The guide planes were evaluated for parallelism.

2.2. *Clasp fabrication*

To standardize the position of clasp arm undesirable undercut areas were blocked out with the sculpturing wax (Crowax, Renfert, Hilzingen, Germany) with approximately 2 mm surrounding thickness. Impressions of each model were made

Table 2 – Injection parameters for thermoplastic resin clasps.[a]

	POM	PEEK	PEKK
Pre-heating temperature/time	100/30 min	200/20 min	150/30 min
Melting temperature	220 °C	380 °C	325 °C
Pre-injection time	20 min	25 min	20 min
Injection pressure	4 bar	4 bar	7 bar
Post-injection time	5 min	2 min	1 min
Cooling time	60 min	60 min	60 min
Injection device	J-100; Pressing Dental Srl, San Marino, Italy	Thermopress 400 injection molding system; Bredent	Thermopress 400 injection molding system; Bredent

[a] According to the manufacturers.

in polyether impression material (Impregum Penta H and L) with custom impression trays. Each impression was poured with die-investment material (Obtivest, DeguDent, Hanau, Germany) to make a refractory cast for the CoCr clasps and, with Type IV dental stone (GC Fujirock EP, GC), to make refractory casts for the thermoplastic resin clasps.

For CoCr clasps, preformed half-round tapered clasp patterns (1 mm × 1.4 mm tip) with occlusal rests, and retentive and reciprocal arms (Wachsprofile, Bego) were adapted along the ledges formed with block-out material prior to making impressions. A round wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor. This sprue was later used to maintain clasp test specimens in the masticatory simulator. Each assembly (die and pattern) was invested (Obtivest, DeguDent) according to the manufacturer's instructions and cast in CoCr alloy. Finally the clasps were trimmed, airborne-particle abraded with 50 μm alumina at 0.25 MPa pressure.

For fabrication of the 1.0 mm and 1.5 mm thick thermoplastic resin clasps straight semicircular clasp patterns (Wax patterns, Omnident, Rodgau Nieder-Roden, Germany) (1 mm × 2 mm and 1.5 mm × 3 mm) were used. The previously described wax sprue was connected to the residual ridge base parallel to the path of insertion using a surveyor. The parameters for the injection procedures have been set according to the manufacturers (Table 2).

Eight clasps were fabricated for each material, clasp size, and retentive undercut combination. A total of 112 clasps were made, including 16 CoCr clasps as control group.

2.3. Testing conditions

To perform the retention test, a masticatory simulator (Willytec, Munich, Germany) was used. The machine allows the placement of the clasp to its predetermined terminal position and its subsequent removal from the abutment crown, thus simulating the placement and removal of a PRDP. The models with the crowns were mounted in the masticatory simulator. Each clasp specimen was then placed on the corresponding abutment crown and fixed to the upper part of machine with auto-polymerizing acrylic resin (Technovit 4000, Heraeus-Kulzer) (Figs. 1 and 2). The test conditions were maintained at room temperature (20 ± 2 °C) and wet condition (deionized water). To analyze the data obtained during the simulation test, intervals every 1500 cycles were established. A total of 15,000 cycles were performed, representing the simulated insertion and removal of the PRDP over 10 years, estimating that the patient would perform four complete cycles per day. The test was performed at a constant speed of 8 mm/s. The value established for each time interval corresponded to the arithmetic average of 10 consecutive insertion/removal cycles. The force required for each specimen removal was captured and stored using data acquisition software (LabView, National Instrument, Munich, Germany). Statistical analysis was done with three-way analysis of variance (ANOVA). The significance level was set at 5% ($\alpha = 0.05$).

Table 3 – Mechanical properties of the materials used for clasp fabrication.[a]

	Modulus of elasticity	Tensile strength
POM	2.4 GPa	55 MPa
PEEK	4 GPa	97 MPa
PEKK	4 GPa	89 MPa
CoCr	211 GPa	880 MPa

[a] According to the manufacturers.

3. Results

Figs. 3 and 4 show the changes in retentive force required to remove clasps from the 0.25 mm and 0.50 mm undercuts.

The mean initial retentive force ranged from 1.2 to 3.1 N for the 1.0 mm thick resin clasps and from 4.9 to 9.1 N for

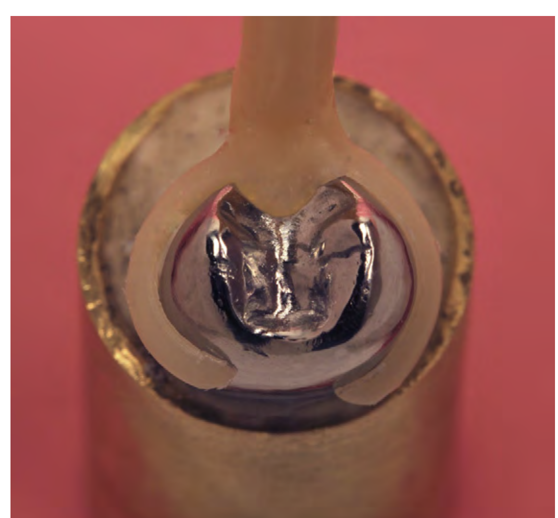

Fig. 1 – Resin clasp on abutment crown.

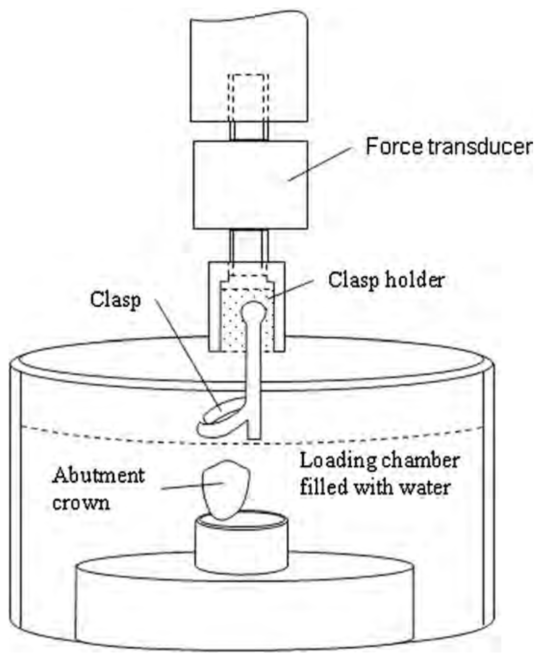

Fig. 2 – Schematic illustration of the assembly (clasp-abutment crown) mounted in the loading chamber.

the 1.5 mm thick resin claps. For CoCr clasps it ranged from 11.3 to 16.3 N. The highest initial retentive force (16.3 N) was recorded in the CoCr clasps with 0.50 mm undercut, and the lowest retentive force (1.2 N) was measured in the 1.0 mm POM clasps with 0.25 mm undercut.

Results of the three-way ANOVA for the resin clasps indicated a significant influence of the three tested factors on the retention at the first period of the cycling ($P \leq 0.001$). PEEK exhibited the highest retention followed by PEKK and POM ($P \leq 0.001$). As well the retentive force required to dislodge 1.5 mm thick resin clasp was significantly higher than the retentive force needed for the 1.0 mm thick clasps. Nevertheless, undercut showed a significant effect on clasps retention with the 0.50 mm undercut provided the higher retention.

The retentive force required for removal of the 1.5 mm thick resin clasps was significantly lower ($P \leq 0.001$) than that required for removal of the CoCr clasps with 0.25 mm and 0.50 mm undercuts (Table 4).

All the clasps exhibited an increase in retentive forces during the first period of cycling followed by continuous decrease till the end of the cycling but it was still significantly not different compared to the initial retentive force ($P = 0.970$).

4. Discussion

Based on the data obtained in this investigation, the CoCr clasps showed significantly higher retention force as thermoplastic resin claps. Therefore, the null hypothesis that there would be no difference in the retentive force between resin clasps and cast CoCr alloy clasps was rejected.

The retentive force is dictated by tooth shape and by clasp design. Tooth shape influences retention by determining the depth of undercut available for clasping [26]. This study was designed to compare the retentive forces of clasps in two different amounts of undercuts. The 0.25 mm undercut was chosen because it represents the undercut commonly used for CoCr clasps, while the 0.50 mm undercut was selected to simulate the cases where clasps should be placed closer to the gingival margin, where undercut tends to be deeper, thereby producing a more esthetic result.

If a clasp is too flexible, it will provide less retention for PRDP. The flexibility of a clasp is dependent on its section, length, thickness and material [26]. In the present study two thicknesses (1.0 mm and 1.5 mm) have been selected to make the thermoplastic resin clasps.

Turner et al. examined the flexural properties of POM to determine the appropriate designs for the PRDP clasp. They suggested that a suitable POM clasp must be approximately 5 mm shorter with a larger cross-sectional diameter (approximately 1.4 mm) in order to have the stiffness similar to a cast CoCr clasp 15 mm long and 1 mm in diameter [8]. Also, Fitton et al. stated that the POM clasps must have greater cross-section area than metal claps to provide adequate retention [7]. The results of the present study verify these findings,

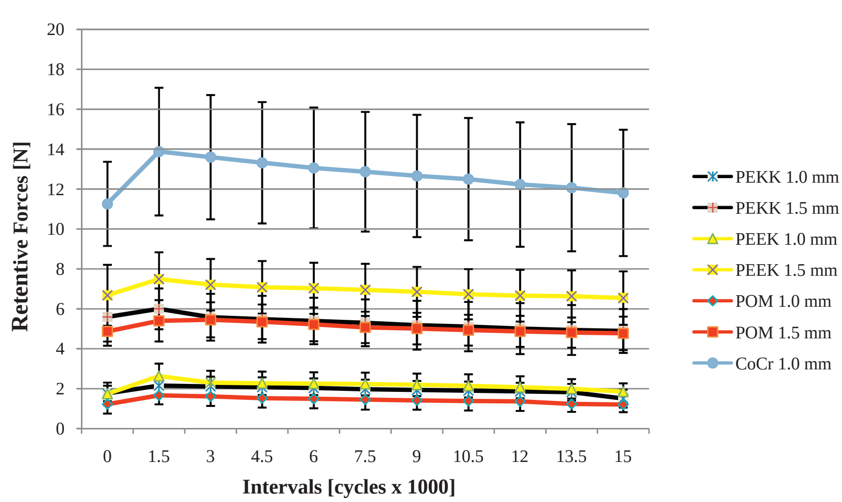

Fig. 3 – Change in forces required to remove clasps with 0.25 mm undercut.

Table 4 – Pairwise comparison of the initial retentive values (N) of Co–Cr clasps and 1.5 mm thick resin clasps.

	0.25 mm undercut		0.50 mm undercut	
	Mean (SD)	P	Mean (SD)	P
CoCr 1.0 mm	11.3 (2.1)	≤0.001	16.3 (3.8)	≤0.001
POM 1.5 mm	4.9 (0.7)		6.6 (1.1)	
CoCr 1.0 mm	11.3 (2.1)	.003	16.3 (3.8)	.001
PEEK 1.5 mm	6.7 (1.5)		8.6 (1.2)	
CoCr 1.0 mm	11.3 (2.1)	≤0.001	16.3 (3.8)	.002
PEKK 1.5 mm	5.6 (1.2)		9.1 (1.7)	

the greatest retentive force for POM clasps was found in the 1.5 mm thick clasps designed to engage the 0.50 mm undercut, the same was for PEKK and PEEK. Thermoplastic resin clasps should be thicker than metal clasps and engage a deeper undercut to gain clinically acceptable retention. This is due to the relatively low rigidity of the thermoplastic resin (elastic modulus; 2.4 GPa for POM and 4.0 GPa for PEEK and PEKK as compared to 240 GPa for CoCr alloy) [8,10].

It could be claimed that the two bulkier designs which used to make the thermoplastic clasps could prevent the self-cleaning functions and cause more plaque accumulation. However, several studies showed that if plaque control is established and a regular recall system with control, re-instruction and re-motivation is provided, removable partial dentures might not cause damage to the periodontium [27,28]. Shimura et al. found that the plaque formation on the buccal surface is not dependent on the type or placement of clasps, and suggested to prepare the guide plane as close to the gingival margin as possible to reduce the plaque accumulation on the distoproximal surface [29]. However, clinical studies are recommended to evaluate the effect of resin clasps on the plaque accumulation on the abutment teeth.

The results of the present study showed that resin clasps of both dimensions had significantly lower retentive force than CoCr clasps. Sato et al. suggested that a retentive force of 5 N is required for adequate function of PRDPs [18]. Frank and Nicholls showed that 3–7.5 N represents an acceptable amount of retention for a bilateral distal-extension PRDP [23]. In the current study, the mean retentive force for the 1.0 mm thick thermoplastic resin clasps at the end of the cycling test ranged from 1.7 N to 3.7 N, and for the 1.5 mm thick clasps from 5.4 N to 10.8 N. These results reveal that thermoplastic resins could be used in the fabrication of clasps for PRDPs, as they provide adequate retention for PRDP even after 10 years of stimulated use.

Previous studies on the fatigue resistance of CoCr clasps have indicated a loss of retention because of permanent deformation of the metal [22,24]. The results of this study showed no significant difference between the initial and the final retention. This can be explained by the method which is used to carry out the test. In the present study, the simulating test and the measurement of retentive forces have been performed using the same machine; the clasps have been fixed in the upper part of the testing machine using auto-polymerizing acrylic resin. These two procedures may reduce or eliminate all possibilities of torquing and ensured a straight path during cycling, and, thus, may have influenced the experimental outcome positively. Any excess torquing may affect the outcome of clasps negatively [20]. The increase of retention force observed in the first period of simulating could be explained by the wear between the crown and the inner surface of the clasp, which might have induced an increase in roughness of these two components during the first period of cycling, after that, the increased wear, caused a decrease in retention.

Limitations of this study include that the test was performed in a rigid system. The results under clinical conditions may not be the same due to the presence of periodontal ligament which allows physiological mobility of natural teeth. In the mouth, there are usually different insertion and removal paths, since obtaining truly effective guide planes is

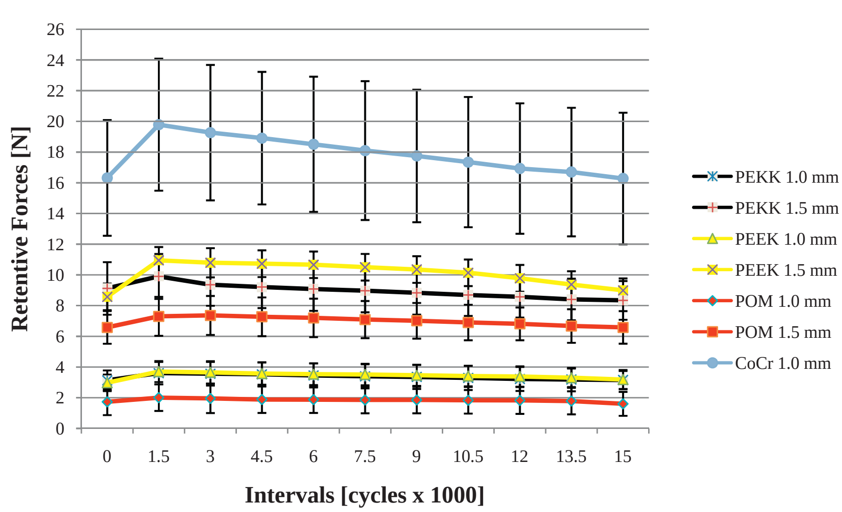

Fig. 4 – Change in forces required to remove clasps with 0.50 mm undercut.

conditioned by anatomical aspects. Additionally, patients can change the path used to move the denture at each insertion and/or removal cycle, producing greater loads on the tooth, thus leading to permanent clasp defects in a short period of time. These factors may have increased the retentive force values for the test compared to actual clinical usage. Therefore, further studies are needed, in conditions closer to clinical situations.

5. Conclusion

Within the limitation of this study, it was found that the thermoplastic resin clasps maintained retention over 15,000 joining and separating cycles with significantly lower retention than CoCr clasps. However, the retention of adequately designed resin clasps might be sufficient for clinical use.

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