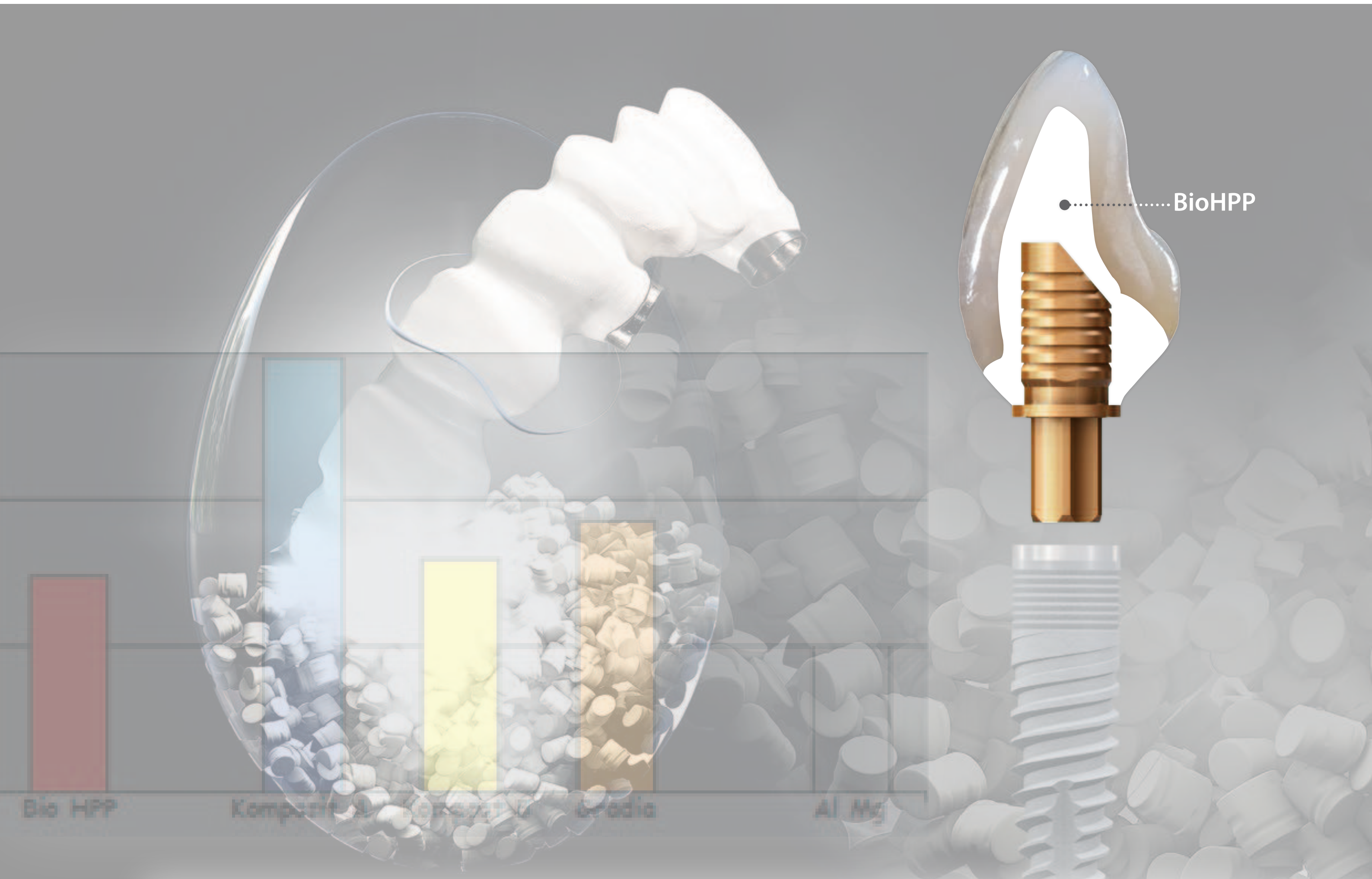
SUMMARY OF SCIENTIFICAL RESULTS

BioHPP Study Results 2011-2018



BioHPP – The New Material Class in Prosthetics

Contents

Foreword

Physiological scaffold materials adapted to nature – from PEEK to BioHPP

For over 35 years, PEEK has been used as an implant material in human medicine (finger prostheses, intermediate spinal bodies, and hip joint prostheses). The advantages lie in the highly bio-compatible material properties that allow the prostheses to be integrated into the bone. The mechanical material properties are also highly similar to those of the bone skeleton.

PEEK (polyetheretherketone) is a high-performance polymer from the group of polyaryletherketones and is their most important representative. PEEK is a bioinert material that can be used for implantation in the human body. Its elasticity is more similar to that of human bone than titanium-based alloys, such as those used to replace joints, for example.

If PEEK is used as implant abutment instead of such alloys, this reduces the stress on the bone and the tissue compared with metallic materials. As a result, the risk of bone resorption by implants is reduced. Whereas PEEK has been used in surgery for the indications mentioned above for decades, the material has not been used in dentistry for that long. For the prosthetic supply of medical devices based on PEEK, bredent distributes the material BioHPP in the form of pellets, granules, and milling blanks for processing in the dental laboratory.

BioHPP is a specially modified PEEK enriched with inorganic fillers (approx. up to 30%) and approved for dental applications (Medical Devices Act Class IIb). Bredent thus modified the material-specific properties for use as a scaffold material. The biological properties of the base polymer PEEK were not changed but rather significantly improved in terms of material combinations (e.g. veneering composites and adhesive composite systems) and mechanical properties (e.g. elasticity and bending strength).
This summary of various scientific studies shows the properties and the advantages compared to the usual materials such as zirconia dioxide and dental casting alloys.

Your bredent group

Classification of industrial polymers

The term "high-performance polymers" is often misunderstood in the dental industry. From a chemical point of view, the term is derived from the continuous service temperature, which is above 150°C. In combination with the excellent mechanical properties PEEK is in a class of its own compared with standard and technical polymers.

Thanks to the admixture of inorganic fillers, BioHPP is also in the highest class and far exceeds the material-specific properties of PEEK. With its mechanical advantages (e.g. excellent polishability and composite materials), BioHPP is particularly suitable for use in the dental sector.

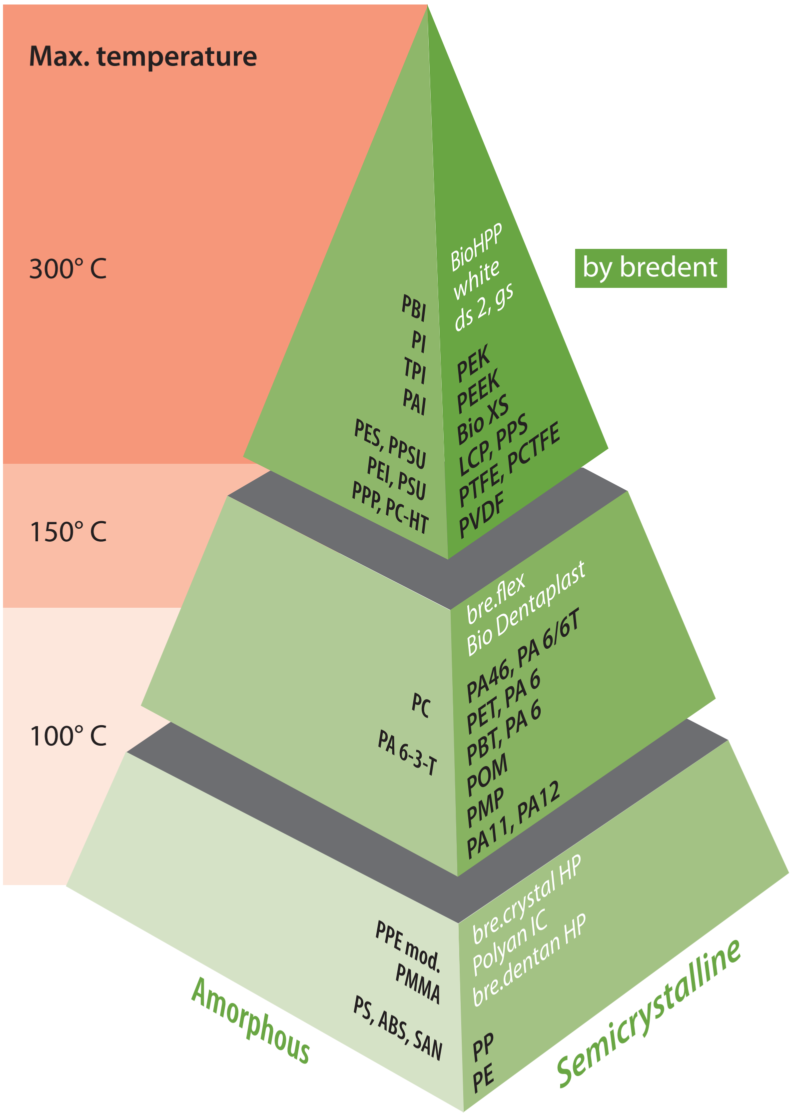


Fig. 1: The polymer pyramid illustrates the classification of standard polymers, technical polymers, and high-performance polymers.

1 Determination of material properties of BioHPP[1,2]

Dr Roland Göbel, Dr Angelika Rzanny
University Hospital of Jena
Polyclinic for Dental Prosthetics
and Materials Science

The aim of the work was the investigation of the PEEK plastic BioHPP in the colour white. In addition to bending strength, modulus of elasticity, and hardness, its surface, abrasion, and discolouration properties as well as the bond strengths to form cement composites were investigated.

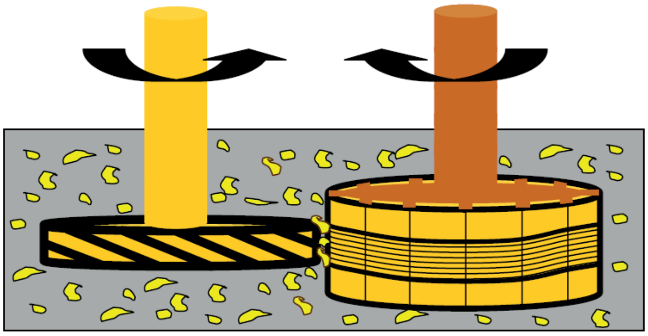


Fig. 2: Principle of the 3-media abrasion machine developed according to De Gee (Willytec). [3]

Abrasion resistance of BioHPP compared with various veneering composites and amalgam as a filling material

The abrasion resistance was determined using the 3-media abrasion machine (Willytec) according to the abrasion method developed by De Gee. The specimen wheel was equipped with test specimens; an AlMg alloy of the same hardness as amalgam and Gradia dentin mass was used as a reference material. After grinding in the equipped wheel with a coarse and then fine diamond grinding wheel (contact pressure = 15 N), an abrasion test with a contact pressure of 20 N was carried out. The intermediate medium was dentifrice body HS RMS 11000015. The abrasion tendency of BioHPP (Fig. 2) was comparatively low at 1.5 (AlMg alloy of the same hardness as amalgam = 1). From this, it can be deduced that occlusal surfaces made of BioHPP are less abrasively damaged than with other veneering resins. Conversely, the vital teeth in contact with BioHPP are also less worn than is the case with ceramic materials, for example.

Grade of abrasion

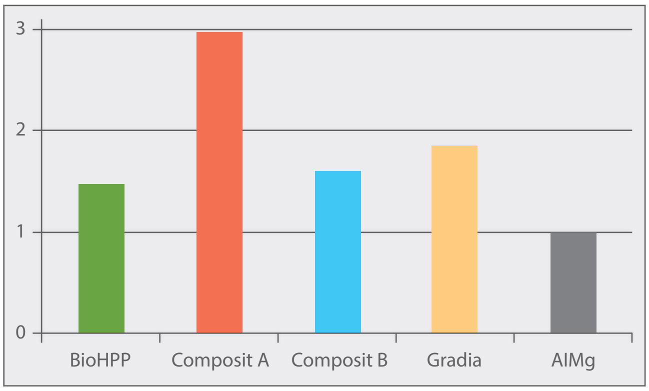


Fig. 3: Abrasion tendency of BioHPP and various veneering composites compared with AlMg alloy. [4]

1) See Rzanny A, Goebel R, Küpper H. PEEK – ein interessanter Werkstoff und alternatives Gerüstmaterial. ZWR – Das Deutsche Zahnärzteblatt. 2015;123:608-13.
2) See.. Rzanny A, Göbel R, Fachet M. BioHPP – Zusammenfassende Ergebnisse der werkstoffkundlichen Untersuchungen. Jena: Friedrich-Schiller-Universität; 2013.
3) Rzanny, Werkstoffkundliche Untersuchungen, 2013, 5.
4) Rzanny, PEEK – ein interessanter Werkstoff, ZWR 2015, 611.
5) Rzanny, Werkstoffkundliche Untersuchungen, 2013, 9.
6) ibid., 12.

Discolouration ΔE

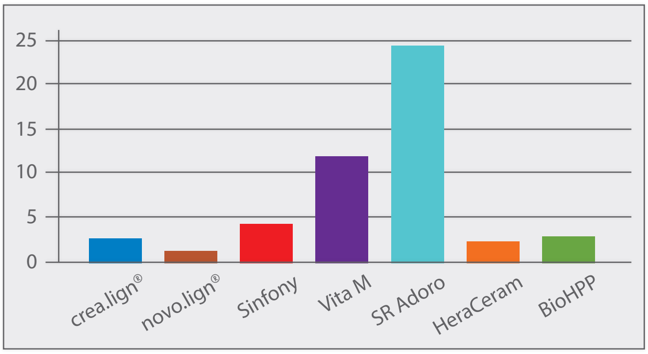


Fig. 4: Abrasion tendency of BioHPP and various veneering composites compared with AlMg alloy.[5)]

Surface roughness [µm]

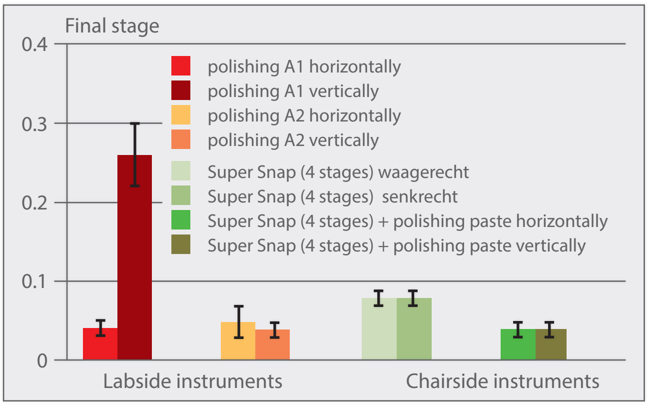


Fig. 5: Surface roughness of BioHPP horizontal to the machining direction after different polishing[6)]

Dental machining using hand piece (A1/A2):

1. Carbide end mill (coarse cross cut) (REF H194GH40), low contact pressure, 6,000–8,000 rpm
2. Diagen Turbo Grinder, green (REF 34000150), low contact pressure, 6,000–8,000 rpm
3. Ceragum rubber polishing roller (REF PWKG0650), very light contact pressure, 6,000–8,000 rpm
4. Goat hair brush with pumice stone, fine, small (REF 35000550), 5,000 rpm
5. Goat hair brush (REF 35000550) with Abraso Starglanz high gloss polishing paste, cotton buff (REF 35000650) without polish, 6,000–8,000 rpm

Dental treatment with the contra-angle on the dental unit (B): Super Snap polishing discs (Shofu) in the order: coarse, medium, fine, superfine, DirectDia polishing paste on Super Snap Buff Disk (Shofu) with 10,000 rpm.

Discolouration tendency of BioHPP

To determine the exogenous tendency to discolouration, the test specimens were stored for 4 weeks at 37°C in various preparations (coffee, tea, tobacco, red wine, methylene blue, and distilled water). The measurement of discolouration in comparison to the control (stored dry and dark at 37°C) was performed with the ShadeEye-NCC (Shofu, Ratingen). This works on the basis of the CIELAB system and determines the L*a*b* values, which provide information on hue, brightness, and saturation. The scatter of the L*a*b* values around the control sample was calculated on the basis of the standard deviation. The resulting value is called degree of discolouration V. In order to record the total deviation of the discoloured specimen from the control specimen, the colour difference ΔE was calculated from the 3 components. ΔE is a measure of the visually discernible colour difference under the most favourable conditions.

The average exogenous discolouration tendency of the media examined (coffee, tea, tobacco, red wine, and methylene blue) was very low for novo.lign and BioHPP (1.2 and 2.8, respectively; Fig. 4).

Surface roughness and polishing properties of BioHPP

A very smooth surface is the most important prerequisite for a low plaque build-up. This is the only way to keep the denture clean for a long time and make cleaning easier. Test specimens of 20 mm length, 10 mm width and 3 mm thickness were used to determine the surface quality, and the surface was treated as follows: A distinction was made between a dental technique without circular movement (A1), another dental technique with circular movement (A2) and a dental processing method (B).

The surface quality achieved surface roughness of 0.04 µm (Fig. 5) using both dental-technical and dental variants. In order to achieve this high surface quality, the polishing strategy had to be adhered to very precisely. With conventional polishing strategies for composites it is impossible to achieve an acceptable surface roughness.

Structure analysis

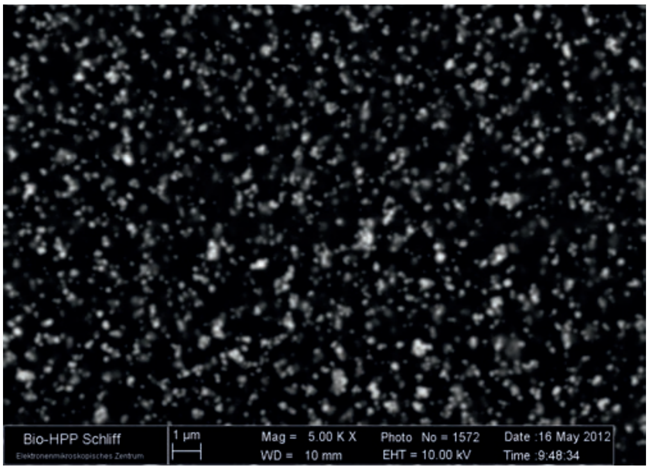


Fig. 6: Structure of BioHPP.[7)]

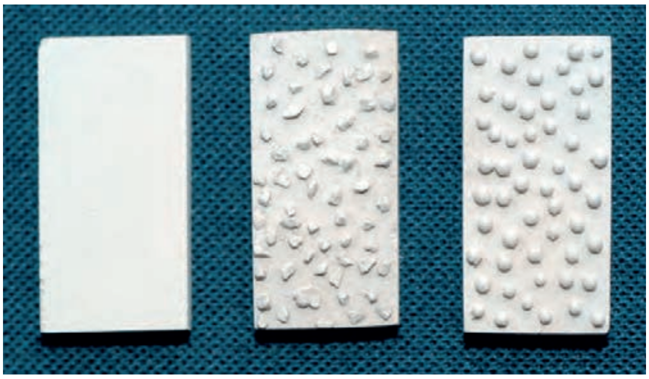


Fig. 7: Test specimens with differently prepared surfaces of BioHPP (1: ground, 2: splinter, 3: beads).[8)]

Compression shear strength[MPa] BioHPP milled – DTK adhesive

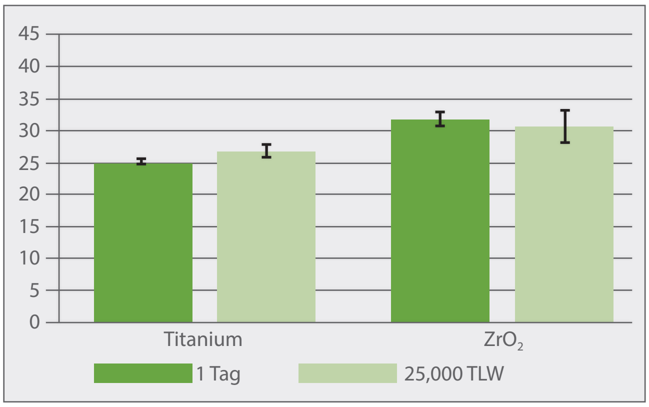


Fig. 8: Pressure-shear strength of the composite variants BioHPP/DTK adhesive/titanium and BioHPP/DTK adhesive/circonium dioxide after 1 day and 25,000 TLW.[9)]

Measurement of the composite strengths of BioHPP sample plates to various dental materials

The pressure shear tests were carried out with the Zwick Z 005 universal testing machine. The traverse speed was 1 mm/min. One to three test specimens (initial value) or four test specimens (artificial ageing) were produced per series. The adhesive strength of BioHPP was thus determined for the veneering composite combo.lign and the cement composite DTK adhesive. The test specimens made of BioHPP were produced using different processes. In the first process, mechanical macro retentions in the form of beads and crystals were applied using the pressing technique. In the versions milled using CAD/CAM, the specimen surfaces were smooth.

The platelet surface of all samples was blasted with corundum (110 µm; 3 bar) see also fig. 7 and 9a:

1. BioHPP (milled): 20 × 10 × 2mm, visio.link (90 s Dentacolor XS). A metal ring was placed on the BioHPP surface and combo.lign was applied. This was stored for 10 min in the dark and then exposed to Dentacolor XS for 90 s.

2. BioHPP (pressed with beads): 20 × 10 × 2 mm, visio.link (90 s Dentacolor XS), combo.lign opaque (90s Dentacolor XS), combo.lign was applied to a metal ring placed on the BioHPP surface. This was stored for 10 min in the dark and then exposed to Dentacolor XS for 90 s.

3. BioHPP (pressed with crystals): 20 × 10 × 2 mm, visio.link (90 s Dentacolor XS), combo.lign opaque (90 obligations Dentacolor XS), combo.lign was applied to a metal ring placed on the BioHPP surface. This was stored for 10 min in the dark and then exposed to Dentacolor XS for 90 s.

The bond strength of BioHPP to the cementing composite combo.lign is shown in Fig. 9a. The pressure-shear strength of 25 MPa remained stable even after artificial ageing. The macro retentions applied (beads, crystals, see Fig. 7) led to a significant increase in the network to up to 40 MPa. The adhesive strengths of BioHPP on titanium and zirconia dioxide surfaces determined in vitro (adhesive: DTK adhesive) is shown in Fig. 8. For titanium and zirconia dioxide, 25 and 32 MPa, respectively were measured; this did not show any significant decrease in adhesion, even after 25,000 TLW.

Compression shear strength [MPa] BioHPP – combo.lign

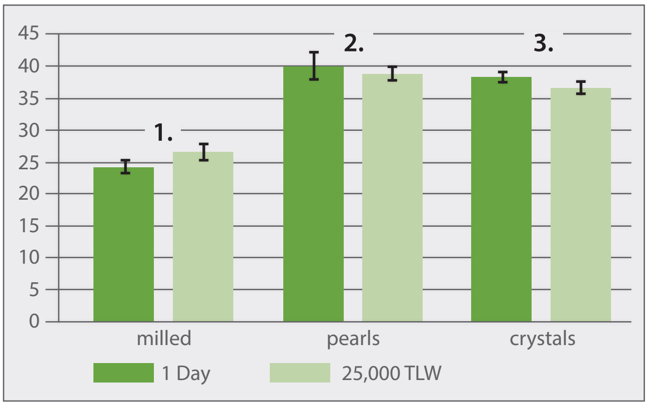
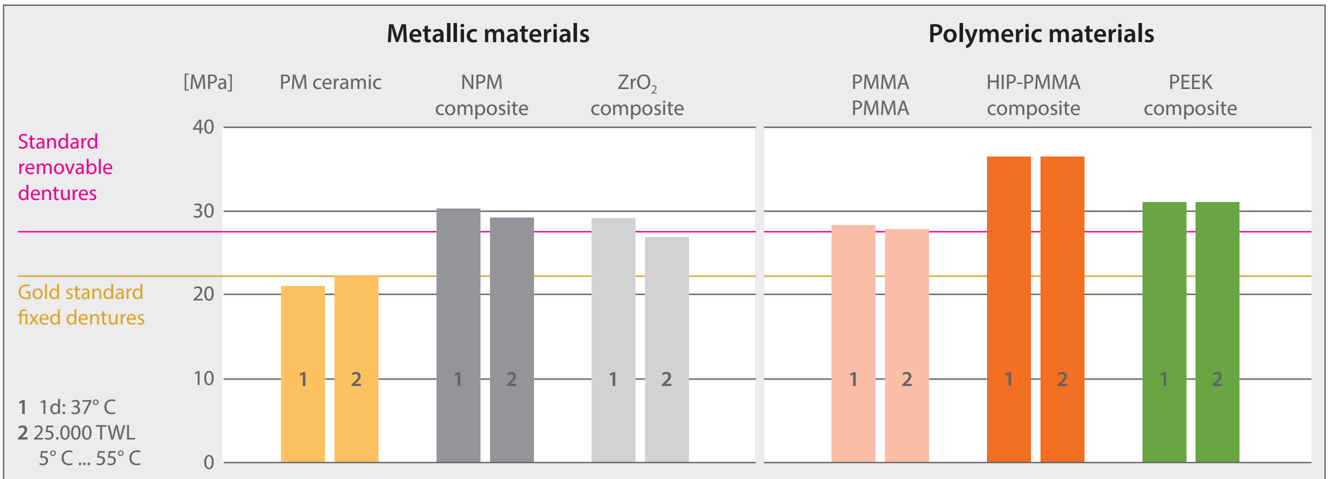


Fig. 9a: Pressure-shear strength of BioHPP to combo.lign on differently prepared surfaces after 1 day and 25,000 TLW.[10)]

Common framework materials such as precious metal, zirconia dioxide or NPM show similar or lower bond strength values (Fig. 9b). The composite strength of the materials to the veneering material combo.lign was also tested after artificial ageing and 25,000 temperature load changes. A clinically safe level of bond strength according to DIN EN ISO 10477:2005-01 is achieved at 20 to 22 MPa.

Editor's note: "A good bond to both the veneering material and the fixing material is decisive for the wearing time and durability of the denture. Increasing the surface roughness is a necessary prerequisite for good adhesion".



Scaffold	Bio Keramikgold G	Wirobond C	Vita In-Ceram YZ	Vita CAD - Temp	novo.lign	BioHPP
Primer		MKZ Primer	MKZ Primer	Palabond	visio.link	visio.link
Opaque	Duceram Plus	crea.lign Opaker	crea.lign Opaker			Opaquer combo.lign
Test plastic/veneering material	combo.lign	combo.lign	combo.lign	PalaXpress	combo.lign	combo.lign

Fig. 9b: Combo.lign compression shear strength to metallic framework materials and polymers.[11)]

[7)] ibid., 18.
[8)] Rzanny, PEEK – ein interessanter Werkstoff, ZWR 2015, 612.
[9)] ibid., 612.
[10)] ibid
[11)] See Göbel R, Rzanny A. Verbundfestigkeit zwischen verschiedenen Verblend- und Gerüstwerkstoffen. Darstellung werkstoffkundlicher Untersuchungen zur Verbundkombination dentaler Werkstoffe. Die Quintessenz der Zahntechnik. 2016;42(8):1064-1068.

2 In-vitro-investigations of BioHPP in telescope technology[12)]

Dr. Franz-Josef Faber,
Dr. Hubert Roggendorf,
Dr. Nadine Holzer
University of Cologne
Centre for Oral and
Maxillofacial Medicine

The aim of the present work was to measure the pull-off force of cylindrical single telescopes. The influence of ageing and the hydraulic effect on adhesion were tested.
In this study it was examined which material combinations lead to material abrasion or friction loss taking into account the integration frequency. An optimal material pairing of primary and secondary telescope was derived from these results. The initial pull-off forces were between 2 and 3 Newton. In a single-tooth telescope, a higher value can lead to damage to the periodontium.
In addition, the ideal manufacturing specifications for BioHPP secondary components with regard to the adjustment of embedding material, preheating temperature, and finishing of the inner surfaces were tested and determined.

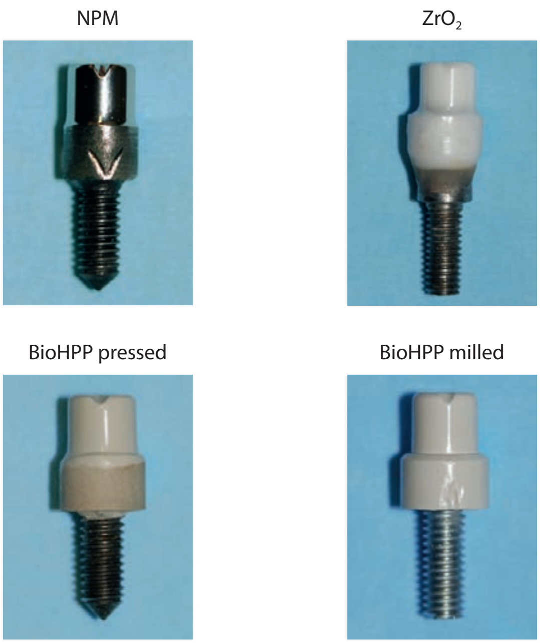


Fig. 10: Primary components made of three different scaffold materials.[13)]

Analysis of friction curves taking into account different dental scaffold materials

The holding force of cylindrical telescopic crowns (diameter = 6 mm, height = 5 mm) was measured dry and under water in the tensile test. To check the influence of aging, the crowns were joined and separated repeatedly (nmax=10,000 cycles). In the course of the first 100 joining cycles, the adhesive force was measured for the first time after 10 pulls. The holding force was then measured once after 1,000 and 10,000 cycles. For some crowns, the pull-off speed was varied during the first tests (10 to 200 mm/min) in order to check the hydraulic influence on the adhesion of the telescopic crowns.

[12)] See Faber FJ, Holzer N, Roggendorf H: In-vitro-Untersuchungen mit BioHPP in der Teleskoptechnik. Köln: Universitätsklinikum, Zentrum für Zahn-, Mund- und Kieferheilkunde; 2013.
[13)] Faber, In-vitro-Untersuchungen in der Teleskoptechnik, 2013.
[14)] ibid.
[15)] ibid.

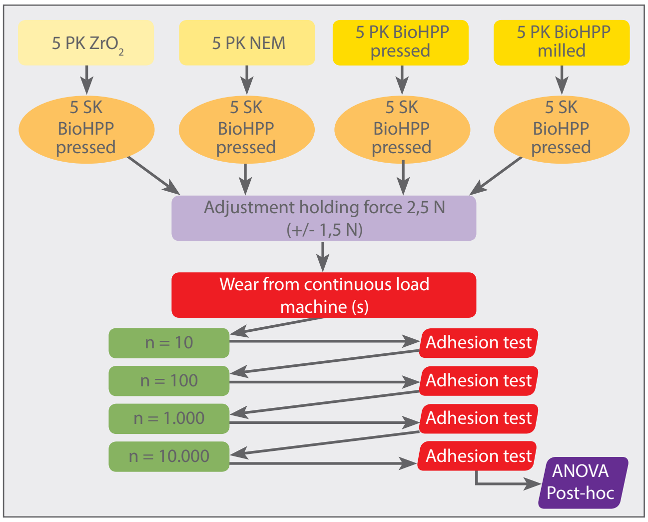


Fig. 11: Material pairing for primary and secondary telescope as well as test procedure.[14)]

Adhesion strength in [N]

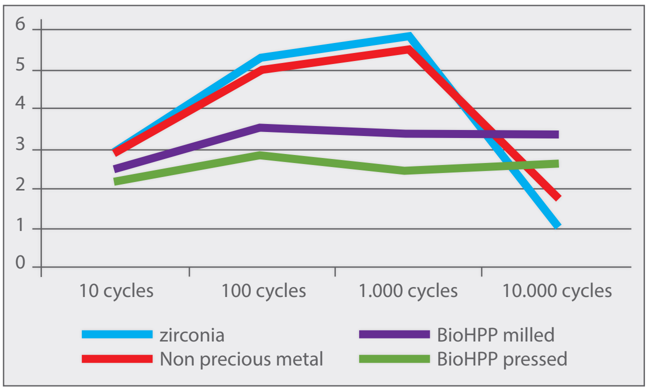


Fig. 12: Pull-off forces (loss of friction) of telescopic crowns made of BioHPP on various primary crown materials (zirconia dioxide, CoCr, BioHPP (pressed), BioHPP (milled).[15)]

After 10,000 wear cycles, all telescope systems showed clinically acceptable pull-off forces on average. The adhesive forces of all test specimens increased during the first 1,000 cycles. After this, the adhesive forces of the secondary components on BioHPP primary components remained more or less constant. The adhesive forces of the secondary components on NPM and zirconia oxide primary components showed a higher variability ranging from 0.72 to 13.15 N. With regard to the adhesive forces measured, the material BioHPP can be used as a definitive telescopic crown material. In combination with primary components made of harder materials such as zirconia dioxide or NPM, a higher scattering of the pull-off forces can be expected. The use of BioHPP primary components with BioHPP secondary components is to be preferred.

Editor's note: "The results show that primary and secondary components made of BioHPP are the best combination in terms of loss of friction. This results in a very simple integration of the denture with optimum adhesion for the patient. The initial friction forces are adjusted by the expansion control during the manufacture of the secondary telescopes. Through the high gloss polishing of the inner surfaces with paint brushes, the total friction can be individually adjusted depending on the number of telescopes. Another advantage of BioHPP telescopes is the simplicity of manufacture. For example, it is possible to produce an alginate impression for fixed primary telescopes at a la ter date".

3 Bond strength between PEEK and veneering resins depending on the surface preparation in the shear test according to EN ISO 10477[16)]

Dr. Franz-Josef Faber,
Dr. Hubert Roggendorf,
Dr. Franziska Elsbernd
University of Cologne
Centre for Oral and
Maxillofacial Medicine

The test of the bond strength between a scaffold material (in this study, three different high-performance polymers) was determined by means of the pressure shear test, taking into consideration EN ISO 10477. The test specimens were made of three different PEEK scaffold materials (PEEK-Optima, BioHPP (milled), and BioHPP (pressed)). All 3 materials were conditioned differently (Al2O3 and Rocatec) and then wetted and polymerised with three different bonding agents. Three different opaques (combo.lign, combo.lign Opaquer, and Sinfony) were then applied to these prepared surfaces. After the measurement, all samples were thermocycled (71 h at 37°C) in order to be able to draw conclusions about a wearing time of 5 years.

High-performance polymers based on PEEK are all opaque and are veneered with veneering composites for aesthetic reasons. The surfaces to be veneered are pretreated differently to increase the bond strength. In this paper, the bond strength of the scaffold material with commercially available veneering materials from various suppliers is evaluated depending on the conditioning.

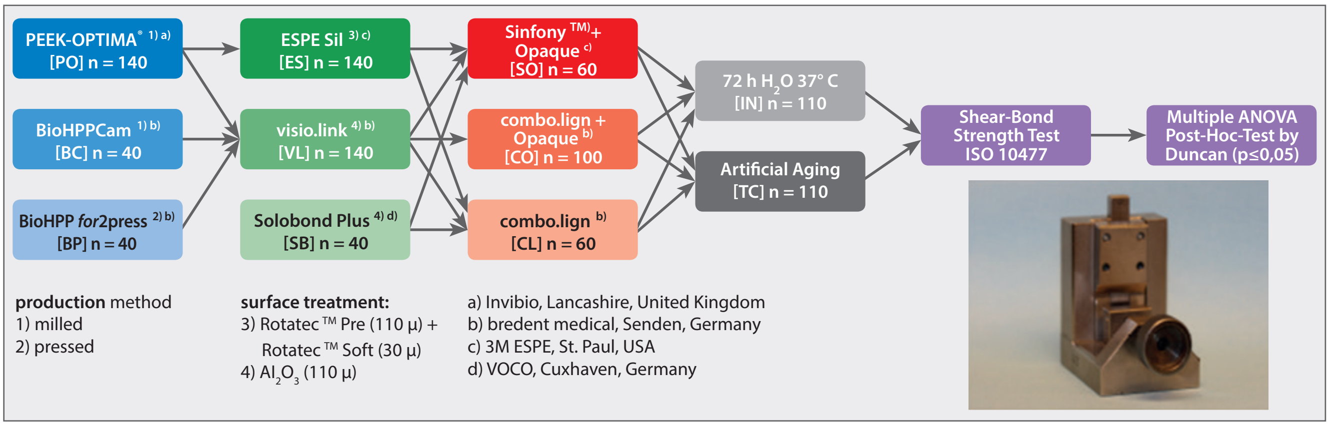


Fig. 13: Material combinations, test procedure, and evaluation.[17)]

[16)] See Schulte F. Verbundfestigkeit zwischen verschiedenen Polyetheretherketonen und Verblendkunststoffen in Abhängigkeit von der Oberflächenvorbehandlung [Dissertation]. Köln: Universität zu Köln; 2015.
[17)] See Elsbernd (Schulte) F, Faber FJ, Roggendorf H. Bond Strength of different Composites to Polyetheretherketon (PEEK) (Poster]. Köln: Universität zu Köln; 2015.
[18)] ibid.
[19)] ibid.
[20)] ibid.

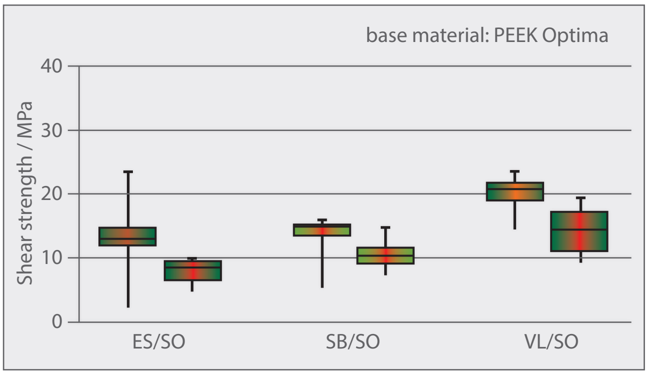


Fig. 14: Depending on the composite system, the bond strength has significantly decreased after ageing because of thermocycling (n = 100). The best results were measured using visio.link ($p < 0.05$).[18]

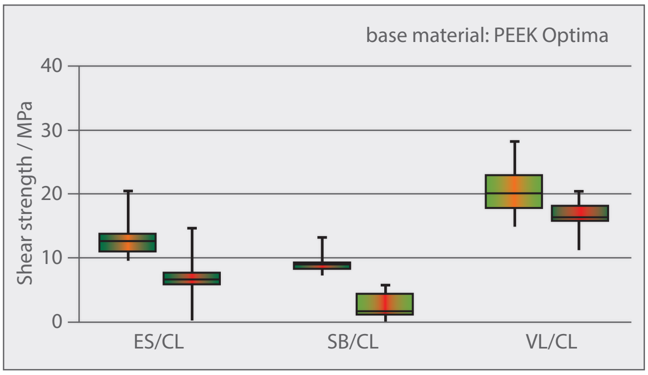


Fig. 15: The lowest bond strength values were measured when Solobond Plus was used after ageing. The results of combo.lign and Sinfony plus opaque are comparable.[19]

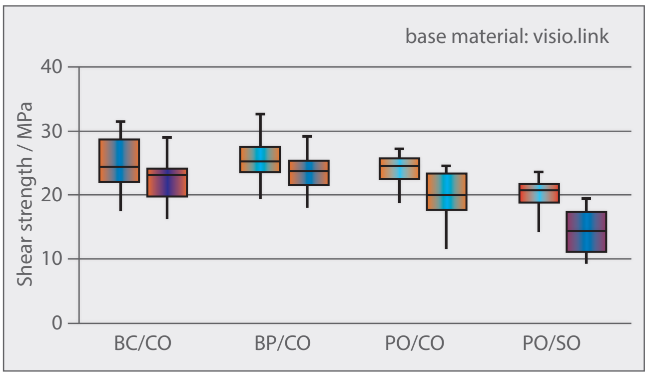


Fig. 16: In combination with the bonding agent visio.link, bond strength values < 20 MPa are achieved. Only with the combination of PEEK Optima and Sinfony veneering composite do the values sometimes fall below 20 MPa after ageing.[20]

Analysis of the bond strength

Taking into account EN ISO 10477, all values are within ranges acceptable for clinical application. The only exception is the material combination combo.lign on BioHPP when using the bonding agent Solobond Plus. Comparable bond strengths to the metal–ceramic systems were only achieved using the bonding agent visio.link.

Editor's note: "The results show that the conditioning of the BioHPP veneering surfaces in combination with a suitable primer and opaquer is extremely important. Because BioHPP is highly opaque when not veneered, it should be veneered in visible areas. Several veneering composites with special bonding agents are available. However, the highest bond strengths are achieved with the combination of visio.link bonding agent with combo.lign opaque. The modulus of elasticity of combo.lign has been adapted to that of BioHPP. This is the only way to avoid tensions and flaking veneers. The use of mechanical retentions additionally ensures the bond strength".

4 Influence of production on the breaking load of three-unit PEEK bridges[21]

Dr. Bogna Stawarczyk,
Dr. Timea Wimmer,
ZT Marlis Eichberger
Ludwig Maximilian University of Munich
Polyclinic for Dental Prosthetics

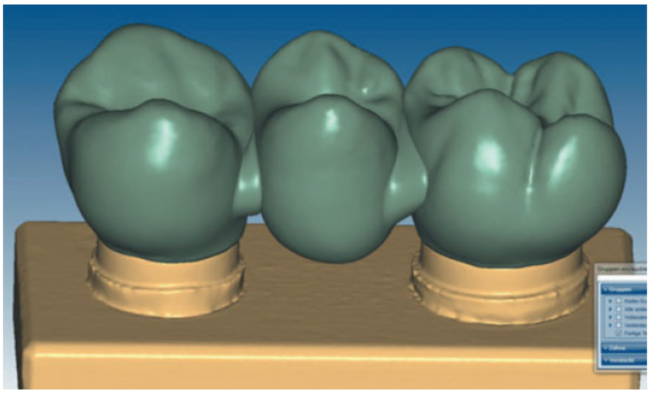


Fig. 17: Constructed bridge on model.[22]

Fig. 18: BioHPP in the 3 different dosage forms: granulate, pellet, and blank.[23]

Fig. 19: BioHPP bridge during the test.[24]

PEEK-based materials are increasingly being used in dentistry. The PEEK material BioHPP, which is reinforced with inorganic substances, can be processed in various ways: BioHPP can be pressed from granules or pellets or milled out of industrially manufactured CAD/CAM blanks. The aim of this study was to compare the stability of bridges made with these three manufacturing methods.

For the examination, 15 congruent bridges were fabricated three times. A standardized bridge model of region 24-26 was the basis (Fig. 17). After scanning (Ceramill Map 400, Amann Girrbach, Koblach, Austria), the bridges were constructed (Ceramill Mind, Design Software, Amann Girrbach) with a connector cross-section area of 16 mm^2. The occluso-gingival height of the connectors was 4.45 mm; the vestibulo-oral width was 3.60 mm. A slight indentation was constructed on the occlusal surface of the pontic so that a steel ball with a diameter of 5 mm was perfectly positioned at this point to determine the breaking load. (Fig. 19).

This ensured a 3-point contact between the steel ball and the occlusal surface. With this data set, 15 bridges from the BioHPP blank (breCAM.BioHPP, bredent) and 30 bridges made of wax (breCAM.wax, bredent) were form ground on the milling machine (ZENO 4030 M1, Wieland Dental + Technik, Pforzheim).
According to the manufacturer specifications, supply channels to the object were waxed onto the wax bridges. The wax bridges were randomly divided into two groups and embedded with special muffles for BioHPP granules (bredent) or BioHPP pellets (bredent) (Brevest for2press, bredent).

[21] See Eichberger M, Wimmer T, Stawarczyk B. Sind die Eigenschaften von BioHPP-Restaurationen immer gleich oder hat die Verarbeitungstechnik einen Einfluss? Untersuchung anhand der Stabilität von Brücken. Die Quintessenz der Zahntechnik 2014; 40:588-98.
[22] ibid., 591.
[23] ibid., 590.
[24] ibid., 593.
[25] ibid., 595.
[26] ibid., 594.
[27] ibid., 594.
[28] ibid., 595.

	Product	Manufacturer	Lot number	Composition
Bridge material	breCAM.BioHPP Blank	bredent Senden	381115	Polyether ether ketone with 20% (by weight) inorganic content
	BioHPP Pellets		379806	
	BioHPP Granules		381125	
Fixing material Variolink II	Variolink II	Ivoclar Vivadent Ellwangen	R35481/P84939	Bis-GMA, UDMA, TEGDMA inorganic fillers (barium glass, ytterbium trifluoride, Ba-Al fluorosilicate glass, spheroidal mixed oxide), catalysts, stabilisers, pigments

Fig. 20: Summary of all materials used.[25)]

Breaking load (N) of three-unit bridges

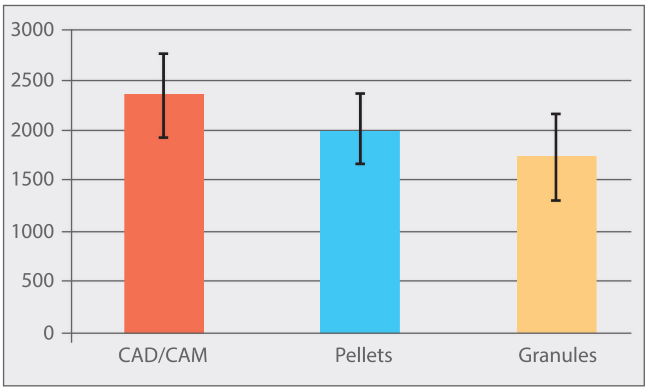


Fig. 21: Bar chart (mean value, standard deviation) of the breaking load values of the differently manufactured congruent bridges.[26)]

	Mean value	Standard deviation	Min	Median	Max	Weibull module
CAM.BioHPP blank	2.354	422	1.571	2.384	3.169	2.527
BioHPP pellets	2.011	353	1.388	2.026	2.660	2.155
BioHPP granules	1.738	439	1.187	1.591	2.631	1.902

Fig. 22: Descriptive statistics with significant differences in the breaking load values of the bridges and the Weibull distribution (all values in Newton).[27)]

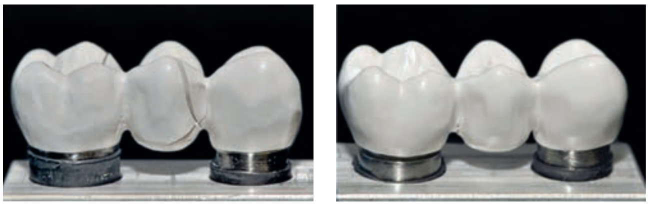


Fig. 23: Left: spontaneous fracture of a milled breCAM.BioHPP bridge; right: plastic deformation of a bridge made of BioHPP granulate.[28)]

After the breaking load measurement, the values were statistically evaluated using the single factor ANOVA and the Scheffé post-hoc test. In order to define and compare the reliability of the bridges, the Weibull statistics (Weibull module) were also calculated. In all tests, p-values of less than 5% were considered statistically significant. The data were analyzed with the statistical program SPSS, Version 20 (SPSS INC, Chicago, IL, USA).

Bridges machine-milled out of BioHPP blanks and bridges pressed from pellets showed higher mechanical stability than those pressed from BioHPP granules. Another advantage of CAD/CAM blanks is the industrial production of the material with a constant quality without porosity and inclusions. For BioHPP, the advantages of pressing technology are indication areas that are difficult to implement mechanically using CAD/CAM. Regardless of the manufacturing method, the three-unit PEEK/C bridges investigated delivered promising breaking load values for clinical application.

Editor's note: "The high breaking load values can be achieved only with ceramic reinforced PEEK variants. The inorganic fillers are largely responsible for this. Comparable investigations of PEEK measured fracture loading values of 1.360 N. With the pressing technique, even more bond strength can be achieved by using mechanical retentions. Added to this is the greater flexibility in the fabrication of larger scaffold structures. The pressing technique also allows the fabrication of individual abutments using the overpressing process. Another advantage of the pressing technique is the production time, especially for larger scaffold constructions".

5 Cleaning study of the scaffold material BioHPP[29,30)]

Dr. Bogna Stawarczyk,
Dr. Sina Heimer,
Dr. Anja Liebermann,
ZT Marlis Eichberger
Ludwig-Maximilians-University of Munich
Polyclinic for Dental Prosthetics

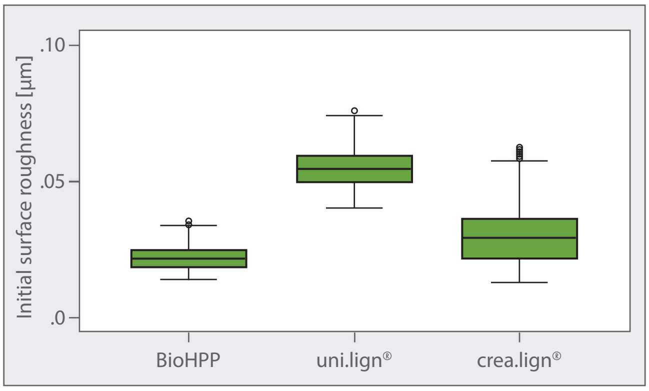


Fig. 24: Initial surface roughness in µm.[31)]

BioHPP

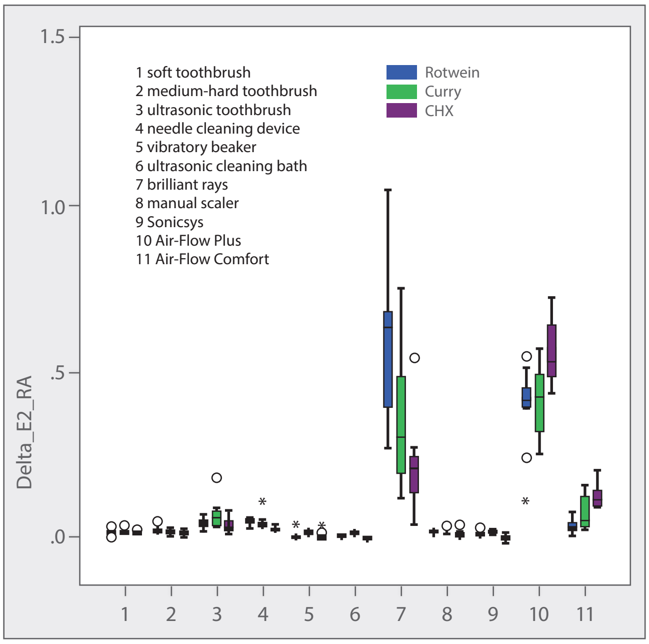


Fig.25: Roughness measurement after the first cleaning in µm.[32)]

This study examined the most suitable cleaning methods with regard to the tendency to discolouration. The commercial cleaning methods were divided into the areas of dentist, dental technology, and the possibilities of the patient in order to derive appropriate recommendations.

First, the test specimens (15 × 3 mm) were produced according to the manufacturer's specifications. All test specimens were polished to a high gloss finish according to a material-specific polishing protocol. The quality of the polish was measured with a laser scanning microscope (Fig. 24). After the measurement all samples were stored in different suspensions (red wine, curry, chlorhexidine) at 37°C for 7 days. The samples aged in this way were measured with a colorimeter. This was followed by the cleaning of the samples using the various cleaning methods and the final measurement, indicating the roughness and degree of discolouration.

The surface of the scaffold material BioHPP can be polished significantly better than the surface of uni.lign and crea.lign. Furthermore, significantly fewer discolourations were detected with BioHPP than with uni.lign and crea.lign. The scaffold material can also be returned significantly better to its original colour by cleaning. The following methods have proven to be most suitable for cleaning BioHPP and uni.lign:
Patient: soft and medium-hard toothbrush
Labside: Needle cleaning and vibratory beaker
Chairside: Air-Flow Comfort and Air-Flow Plus

29) See Heimer S. Polierbarkeit und Reinigungsmethoden des Hochleistungswerkstoffes Polyetheretherketon (PEEK) [Dissertation]. München: Ludwig-Maximilians-Universität; 2017.
30) See Heimer S. Zwischenergebnisse der Reinigungsstudie des Gerüstwerkstoffes BioHPP. München: Ludwig-Maximilians-Universität; 2014.
31) ibid.
32) ibid.
33) ibid.
34) See Quick Reference Card für die Zahnarztpraxis. Leitfaden zur Orientierung bei der Anwendung von BioHPP. bredent GmbH & Co. KG, Senden; 2017.

BioHPP

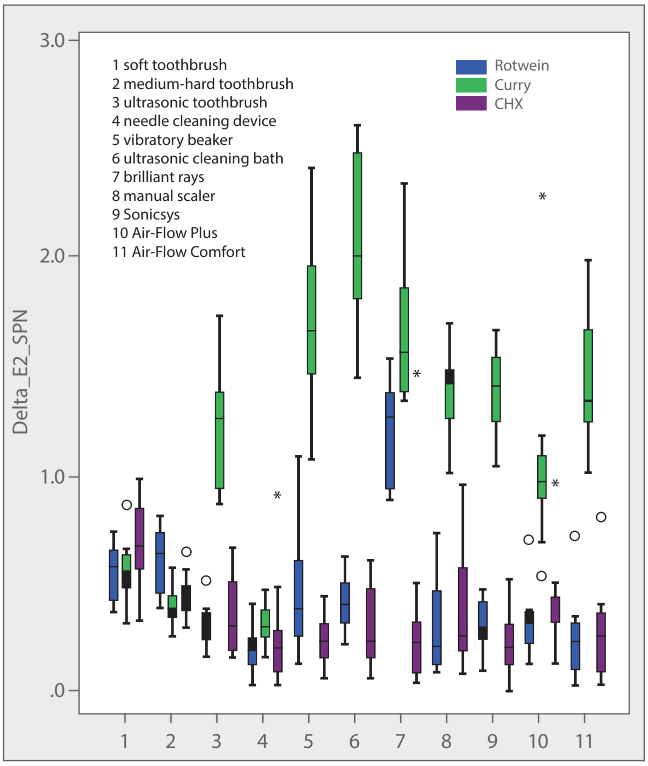


Fig. 26: Discolouration rates of BioHPP according to the respective cleaning procedure.[33)]

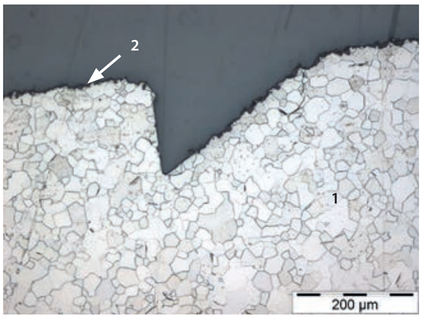
Editor's note: "Patients with BioHPP dentures achieve the best cleaning performance when they use soft to medium-hard toothbrushes daily. This type of cleaning does not require roughening and subsequent polishing. The use of an ultrasonic tooth bust is not recommended because this leads to rougher surfaces. For the dental laboratory, the ultrasound baths and needle cleaning devices are best for cleaning dental prostheses made of BioHPP. Here, too, no subsequent polishing is necessary. In the dental practice, BioHPP surfaces can be cleaned with Air-Flow Comfort or Air-Flow Plus. The surfaces are somewhat roughened, which is why a subsequent high-gloss polishing should be carried out. Practical information on cleaning is given in the Quick Reference Card for the dental practice.[34)]

6 Formation of the oxide layer when pressing over pre-fabricated titanium abutments with BioHPP [35)]

Prof. Dr. I.-M. Zylla
University of Osnabrück
Laboratory for Metallurgy and Materials Analysis

HOCHSCHULE OSNABRÜCK
UNIVERSITY OF APPLIED SCIENCES

Fig. 27: Finished elegance titanium bases (left) and after pressing over with BioHPP (right).[36)]



Samples: Order no. 22131878 from 27/09/2013
Modelling: Wax
Etching: Kroll etchant
Enlargement: 100 : 1
Structure: in retention area
1. α - mixed crystal
2. surface α - case free

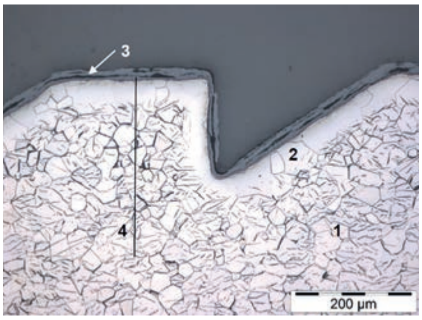
Fig. 28: Light microscopic image of the titanium structure after a thermal load of 630°C.[37)]

In this paper the micro-structure change of pre-fabricated titanium components (Grade 4) used in the fabrication of individual single-tooth abutments using the overpress method was investigated. The processing protocol for overpressing requires an embedding with subsequent heat treatment. This heat treatment can negatively influence the mechanical properties of Grade 4 titanium. In addition, the formation of an alpha-case layer and the formation of gaps between BioHPP and titanium abutment were investigated.

The titanium abutments (SKY elegance) were pressed over with the for2press system and BioHPP according to the manufacturer's specifications. A maximum preheating temperature of 630°C was set for the 1st and 3rd series; a maximum of 850°C was set for the 2nd series. All specimens were embedded in plastic. Micrographs of these were prepared and examined under the microscope for structural changes. In addition, hardness progression measurements were carried out in order to be able to prove a possible hardening and thus structural change. The formation of titanium, aluminium and oxygen has been demonstrated using the EDX linear spectrum.

Two samples per modelation and series (10 samples in total) were examined. Neither the samples of the first nor the last series showed any significant alpha-case layer. There was only a thin layer of titanium oxide.

[35)] See Zylla, IM. Entstehung der Oxidschicht beim Überpressen vorgefertigter Titanabutments mit BioHPP. Osnabrück: Hochschule Osnabrück, Labor für Metallkunde und Werkstoffanalytik; 2014.
[36)] Pictures bredent GmbH & Co. KG, Senden.
[37)] Zylla, Entstehung der Oxidschicht, Osnabrück, 2014, 2.
[38)] ibid., 8.
[39)] ibid., 11



Samples: Order no. 12839958 from 14/03/2014
Modelling: PiKu
Etching: Kroll etchant
Enlargement: 100 : 1
Structure: in the retention area
1. α - mixed crystal with acicular precipitates
2. α - case layer
3. Titanium oxide layer
4. low load hardness-displacement gradient

Fig. 29: Titanium base SKY elegance with marking of the line of the low load hardness in the light microscope.[38)]

Low load hardness – displacement gradient

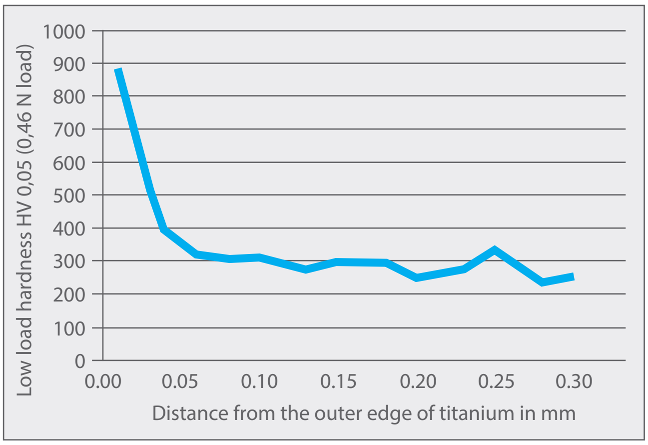


Fig. 30: Results of the low load hardness curve measurement (see also Fig. 29).[39)]

In Series 2, an approx. 40-µm thick alpha-case layer was detected (Fig. 29). This can be seen from the low load hardness values determined (Fig. 30). Overall, the titanium structure underwent major changes. The grains of the alpha solid solution contained acicular oxygen-containing precipitates. These are produced by reaction with diffusing gases at higher temperatures. The relatively high proportion of Al2O3 particles (abrasive) on the abutment surface, which could influence the bond strength, must also be taken into account.

Editor's note: "The examination showed that at a preheating temperature of max. 630°C, no alpha-case layer is formed on the surface of the titanium abutment. An alpha-case layer is undesirable because its high hardness makes it brittle and can lead to cracks and late damage under stress. If the temperature of the pre-heating oven for the embedding mass ring is not controlled and a higher temperature is reached, intermetallic mixed crystals are formed inside the titanium structure. This structural change reduces the mechanical values and can damage the titanium abutment pressed over with BioHPP. The titanium alloy (Grade 4) of the SKY elegance abutment base meets these requirements and can be embedded, pre-heated, and pressed over".

7 In vitro examination of four-unit bridges on plastic dies (TCML and fracture test): Fully anatomical design made of PEEK (milled and pressed) [40]

Prof. Dr. Carola Kolbeck,
Priv.-Doz. Dr. Dipl.-Ing. (FH) Martin Rosentritt
University Hospital of Regensburg
Polyclinic for Dental Prosthetics

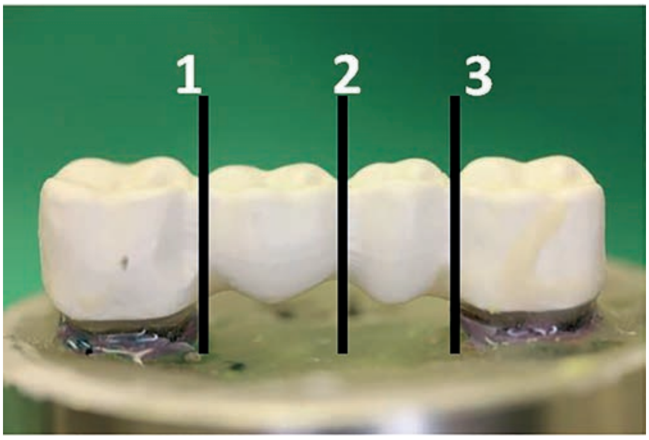


Fig. 31: Dimensioning of the connector areas (black markings).[41]

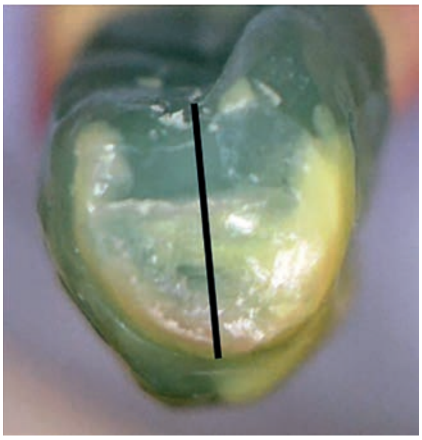


Fig. 32: Dimensioning of a pontic.[42]

The aim of the study was to evaluate the behavior of non-veneered four-unit bridges made of fully anatomical PEEK. The two series to be investigated differed in the PEEK processing. In one series, the bridges were milled from PEEK; in the other series, they were pressed from PEEK. The main focus was on the dimensioning of the connector cross-sections in order to determine the maximum possible and sensible bridge span for definitively fixed BioHPP bridges.

In preparation for the examination, movable socketed plastic abutments with a gap width of 17 mm and a rounded step were manufactured (eight specimens per series). The abutments were then pretreated with Al2O3 at 110 µm/2 bar and H3eliobond (Ivoclar Vivadent). The inner sides of the bridge anchors were also prepared and additionally coated with visio.link (bredent). The bridges were then cemented using Variolink II (Ivoclar Vivadent). The three connector areas of the four-unit bridges (Fig. 31) were designed in the same way for all bridges examined.

The dimensions of the connector areas from palatal to buccal were 4.97 mm (1), 4.44 mm (2), and 4.95 mm (3) on average. The average diameter from occlusal to basal was 3.64 mm (1), 3.91 mm (2), and 3.73 mm (3). The average connector area was 13.55 mm2 (1), 13.59 mm2 (2), and 13.55 mm2 (3). In the area of the pontics, the longest reinforcement section was located centrally in the area of the central fissure up to the basal support (Fig. 32). In previous tests, this design had proved to be optimal with regard to breaking strength.

[40] See Kolbeck C, Rosentritt M. In-vitro-Untersuchung viergliedriger Brücken auf Kunststoffstümpfen (TCML und Bruchtest): Vollanatomische Gestaltung aus PEEK gefräst bzw. gepresst. Regensburg: Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2011.
[41] ibid., 4.
[42] ibid., 4.
[43] ibid., 9.
[44] ibid., 7
[45] ibid., 9.

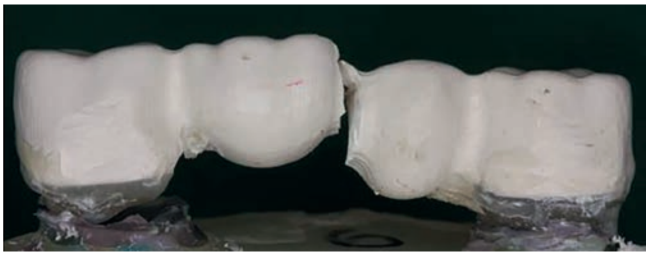


Fig. 33: Fracture of a BioHPP bridge produced by CAD/CAM.[43]

n	Loss of strength without visible damage	Basal crack formation	Scaffold fracture
	1158	1567	–
2	997	1475	–
3	979	1433	–
4	871	1325	–
5	–	1327	–
6	980	1583	–
7	1149	1407	–
8	–	1361	–

Fig. 34: Measured values of the breaking load (in Newton) of pressed BioHPP bridges.[44]

n	Basal crack formation	Scaffold fracture
9	1538	1850
10	1734	1734
11	1540	1638
12	1338	–
13	1855	1868
14	1639	1639
15	1442	–
16	1385	1680

Fig. 35: Measured values of the breaking load (in Newton) of milled BioHPP bridges.[45]

After pre-treatment, the bonded bridges were subjected to artificial aging for a five-year clinical wearing period (1.2 × 106 × 50 N mechanical loads and 2 × 3,000 × 5/55°C thermal alternating loads). The breaking load was measured with a tensile-compression testing machine (Zwick).

The breaking load at which the constructions failed was considered to be the values of the basal crack formation (see Fig. 33–35). Prior to the cracking of the bridges, acoustic failure indications occurred; these may indicate internal stresses of the system. The constructions yielded without visible damage. As a result of the bending of the bridges, veneering resins would have presumably flaked off at these load values.

The force required for basal crack formation was approx. 100 N higher (mean value) for milled bridges than for pressed bridges. It can be assumed that the milled constructions were less elastic (further force build-up after cracking up to the fracture possible) or had less internal stresses (no fracture noises).

With regard to the strength of the bridge constructions, a fully anatomical construction of tooth-coloured bridges made of PEEK is suitable as a possible metal-free restoration alternative.

Editor's note: "Based on this study, the scaffold material BioHPP was approved for the indication of fixed bridges with a max. bridge span of 16 mm of unprepared abutment teeth. In addition, the connector surfaces should not fall below 14 mm^2 in the posterior region. To increase the bond strength between the veneering composite and the scaffold material, the longest reinforcement distance should lie between the central fissure and the basal support in order to be able to absorb the chewing forces well".

8 Checking the pull-off forces between abutment (titanium, BioHPP) and coping (zirconia dioxide, BioHPP) with 4°/8° cone angle for verification of different cements[46)]

Priv.-Doz. Dr. Dipl.-Ing. (FH) Martin Rosentritt
University Hospital of Regensburg
Polyclinic for Dental Prosthetics

In this study, the adhesive strength of different cementing materials (cements, adhesives, composites) depending on different cone angles (4°, 8°) and two different abutment materials (titanium, BioHPP) were investigated. Zirconia dioxide and BioHPP were used as crown materials. From the strength values determined, it was possible to determine whether a certain fastening material is suitable for temporary or definitive applications. The pretreatment of the abutments and crowns with various bonding agents was also analysed.

The titanium abutments were manufactured according to a sample from Straumann as the basis for the pull-off tests. The design resembled a pre-fabricated abutment with 4° or 8° cone angle. The samples were cleaned and eight copings with the different cements were fixed on each abutment. During cementing, the coping was subjected to a constant pressure of 15 N. The cemented samples were stored for 24 h in the incubator at 37°C under a moist cloth. They were then removed axially at 1 mm/min. In all cases, the samples were pre-treated in the dental laboratory using the equipment available there. The titanium abutments and BioHPP caps were blasted with 110 µm Al2O3. Eight test specimens with 4° and 8° were examined per group.

The following cements were tested:
1) Zinc oxide-eugenol-free (Temp-Bond, Kerr) without pre-treatment
2) Zinc oxide-eugenol-free (Temp-Bond, Kerr) with visio.link activation (polymerisation 90 s)
3) Silicone A based (TempoSIL 2, Coltène) without pre-treatment
4) Silicone A based (TempoSIL 2, Coltène) with visio.link activation (polymerization 90 s)

46) See Kolbeck C, Rosentritt M. Versuch zur Überprüfung der Abzugskräfte zwischen Abutment (Titan, Bio HPP®) und Käppchen (ZrO2, Bio HPP®) mit 4°/8° Konuswinkeln zur Verifizierung verschiedener Zemente. Regensburg: Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2013.
47) ibid., 3.
48) ibid., 4.
49) See Quick Reference Card für die Zahnarztpraxis. Leitfaden zur Orientierung bei der Anwendung von BioHPP. bredent GmbH & Co. KG, Senden; 2017.

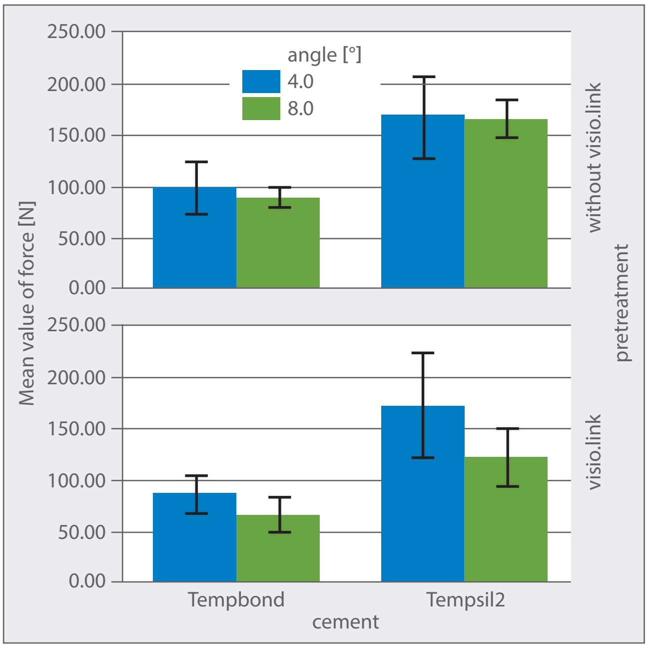


Fig. 36: Pull-off strength of temporarily bonded BioHPP crowns on titanium abutments with 4°/8° cone angle.[47]

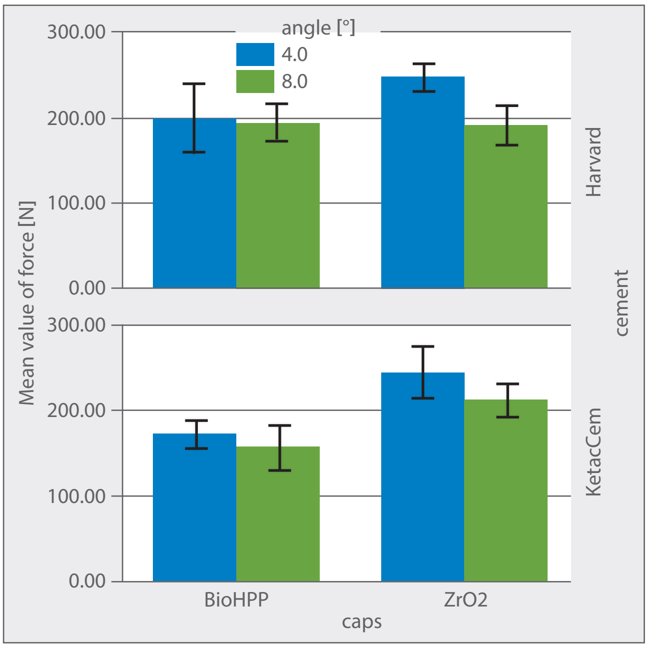


Fig. 37: Pull-off strength of definitively cemented BioHPP/zirconia dioxide crowns on BioHPP abutments (4°/8° cone angle).[48]

In the case of temporary fastening materials, TempoSIL 2 (Coltène) achieved a significantly higher ($p < 0.007$) adhesion force than Temp-Bond (Kerr) in all variants (Fig. 36). Only with TempoSIL 2 was there a significant difference ($p = 0.025$) between the angles of 4° and 8° when visio.link was used.

When Temp-Bond was used, the remaining cement content on the implant was always higher in the comparable groups with one exception (TempoSIL 2: 8°). If visio.link was used, the proportion of cement residue was always higher for Temp-Bond and always lower for TempoSIL 2 compared with the use without bonder.

Analogously, caps made from zirconia dioxide and BioHPP were bonded to definitive cements on BioHPP abutments of the same shape (Harvard zinc phosphate cement, Harvard; glass ionomer cement Ketac Cem, 3M).

During cementation, zirconia dioxide showed significantly ($p<0.024$) higher pull-off values in all groups compared with the cap materials. only at 8° with Harvard mounting were there no significant ($P = 1.000$) differences between BioHPP caps and zirconia dioxide caps (Fig. 37).

After the pull-off test, cement residues of between approximately 10% (Ketac Cem/Zirkondioxid/4°+8°) and 55% (Ketac Cem/BioHPP/4°+8° and Harvard/BioHPP/4°) remained on the implant. When using the BioHPP coping, the residual cement values were generally higher than when using the zirconia dioxide coping. No difference could be found between the variants with 4° and 8°.

Editor's note: "TempoSIL 2 is very suitable for the temporary attachment of BioHPP to titanium abutments. With TempoSIL 2, a pre-treatment with visio.link is not necessary. For the definitive fixation with cements, the zirconia oxide copings on titanium abutments achieved higher pull-off values. There were no differences at 8° cone angle. Acceptable adhesion values were also achieved when using KetacCem. The results of this study were provided as additional information for the dentist in the form of a Quick Reference Card.[49]

9 In vitro examination of four-unit bridges for human teeth (TCML and fracture test) with various scaffold and veneering morphologies[50)]

Prof. Dr. Carola Kolbeck,
Priv.-Doz. Dr. Dipl.-Ing. (FH) Martin Rosentritt
University Hospital of Regensburg
Polyclinic for Dental Prosthetics

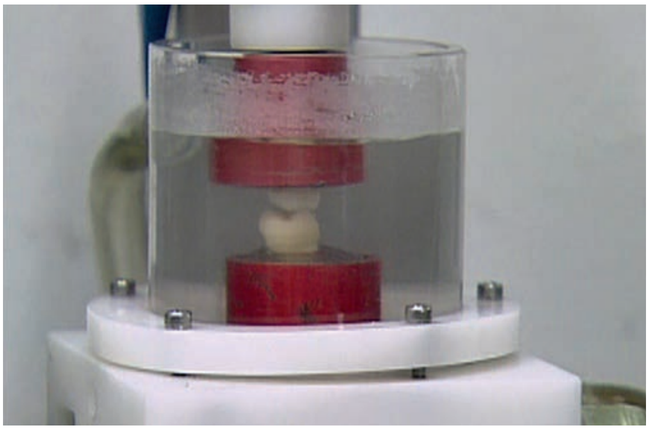


Fig. 38: Sample chamber for chewing load.[51)]

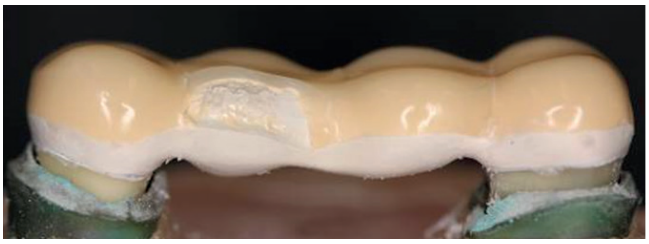


Fig. 39: Bridge after load test with chipped veneer.[52)]

Bridge	F [N] Basal crack opening	F [N] max	Fracture pattern
1	300	1092	Crack formation, no chipping, no scaffold fracture
2	600	2000	Total fracture of veneer/scaffold/abutment
3	800	2150	Veneering fracture
4	1000	1480	Veneering fracture
5	600	1950	Scaffold fracture
6	700	1830	Veneering fracture
7	400	2660	Scaffold fracture
8	1100	1600	Veneering fracture

Fig. 40: Test series with optimised veneer. Force curve [N] during fracture loading and type of failure.[53)]

The aim of the study was to assess the behaviour of four-unit bridges made of BioHPP with plastic veneers. The bridge scaffolds were made from granules from bredent using the for2press process. They differed in scaffold design, veneering material, and vertical abutment tooth height.

Several series of four-unit bridges were created and coupled to simulate physiological tooth mobility. The abutment bases were prepared with a circular step rounded on the inside. The residual stump height varied between 3 and 6 mm. After adhesive cementation of the bridges with Variolink II / Syntac Classic (Ivoclar Vivadent), the scaffolds were veneered with crea.lign (bredent). The samples were then subjected to chewing simulations and fracture tests.

In clinical use, even a basal crack formation was considered a form of failure because composite cracks can contribute to increased plaque retention and increased susceptibility to hydrolysis of the material as well as an increased risk of periodontitis and caries.

The bridge constructions with optimized veneers showed sufficient strength after chewing simulation and fracture tests. In the case of the optimised veneers, care was taken to ensure that they no longer protruded beyond the scaffold and had no sharp-edged ends and points at the connector areas.

Editor's note: "When fabricating fixed bridges made of BioHPP and crea.lign veneers, particular attention should be paid to the morphological design. Breaking strength values between 600 and 1,100 Newtons can be achieved only by avoiding basal cracks. Based on these results and fracture patterns, a recommendation can be given with regard to processing.

[50)] See Kolbeck C, Rosentritt M. In-vitro-Untersuchung viergliedriger Brücken auf Humanzähnen (TCML und Bruchtest): verschiedene Gerüst-/Verblendmorphologien. Regensburg: Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2015.
[51)] ibid., 3.
[52)] ibid., 6.
[53)] ibid., 6.
[54)] See Rosentritt M. In-vitro Untersuchung von dreigliedrigen standardisierten Brücken. Regensburg: Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2011.
[55)] ibid., 3.
[56)] ibid., 3.

10 In vitro examination of three-unit standardised bridges[54)]

Priv.-Doz. Dr. Dipl.-Ing. (FH) Martin Rosentritt
University Hospital Regensburg
Polyclinic for Dental Prosthetics

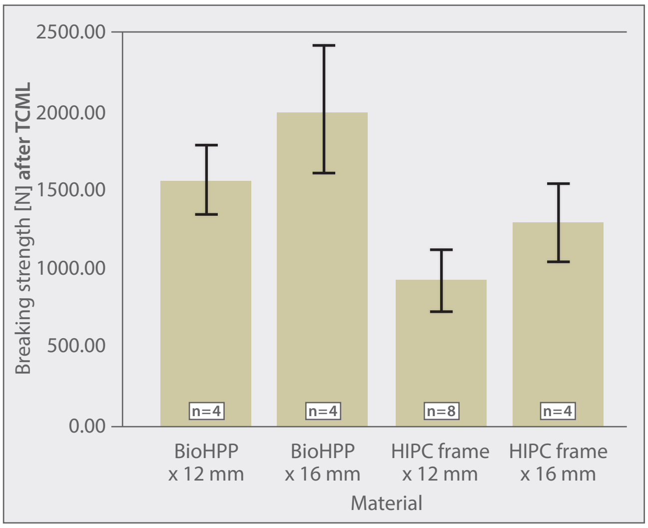


Fig. 41: Breaking force of the various test series.[55)]

Breaking strength [N]	N	Mean value	Standard deviation	Min	Max
HIPC frame connector x 12 mm^2	8	920.3	196.3	602.0	1245.0
HIPC frame connector x 16 mm^2	4	1289.0	249.9	951.0	1538.0
BioHPP connector x 12 mm^2	4	1558.3	224.5	1259.0	1802.0
BioHPP connector x 16 mm^2	4	2004.5	405.7	1642.0	2586.0

Fig. 42: Tabular display of breaking force with mean value, standard deviation, minimum, and maximum.[56)]

The chewing simulator was used to investigate the durability and breaking strength of standardized bridges after thermo-cyclic and mechanical loading. Various connector cross-sections were taken into account.

Identical molar stumps made of PMMA were fixed in pairs in plastic for periodontal support. To simulate a molar gap, the distance between the tooth stumps was approx. 10 mm. Using a plaster model, bredent produced identical standardized bridges from each bridge material. The bridges were fixed at the polyklinik after consultation with Variolink II (Ivoclar Vivadent). The bridges were subjected to a chewing simulation (1,200,000 × 50 N; 2 × 3,000 × 5°/55°C; H2O, 2 min per cycle). A steatite sphere (d = 10 mm) was used as an antagonist. During the chewing simulation, the bridges were checked. Any failure was detected (with the corresponding number of chewing cycles), and the relative survival time was determined.

All the bridges examined survived the chewing simulation without visible damage. However, after simulation, the bridges showed clearly visible signs of wear in the contact area. Overall, the bridges examined showed fracture values that were significantly above the threshold value of 500N, which is usually required for posterior tooth applications. Ceramic restorations have similar or lower fracture values in comparison. In this context, it should be noted that maximum bending of the bridges at the fracture value can lead to clinical restrictions.

Editor's note: "Because of the high breaking strength of BioHPP after chewing simulation (ageing), BioHPP can be used for fixed dentures. The connector cross-sections of 12 and 16mm² allow a delicate scaffold geometry with subsequent veneering. Aesthetics are not compromised in the interdental area. The breaking strength of BioHPP exceeds conventional ceramic scaffold materials by up to 1,000 Newtons".

11 Breaking load and types of failure of differently veneered fixed PEEK restorations[57)]

Chartered engineer Simon Taufall
Ludwig-Maximilians University Munich

In this study, the breaking load of differently blended BioHPP® restorations after artificial ageing was investigated.

For this purpose, 120 identically formed, three-unit frameworks were milled from BioHPP® blanks, which were then blasted with Al_2O_3 particles. The bridge frameworks ranged from one canine tooth over the first to the second premolar. After conditioning with visio.link® primer and combo.lign® opaquer, the researchers divided the samples into four veneering groups:

A) Digital veneering with breCAM.HIPC,
B) Conventional veneering with the flowable composite crea.lign®,
C) Conventional veneering with the paste composite crea.lign®,
D) Gluing the prefabricated veneers novo.lign®.

Framework	breCAM.BioHPP (PEEK), N=120, LOT: 400177								
Veneering	Digital veneering breCAM.HIPC (N=30), LOT: 406700	Conventional veneering		Prefabricated veneers novo.lign (N=30, LOT: Z3304499, Z3843532, Z3849293, Z3303681					
		crea.lign (N=30), LOT: 130513	crea.lign Paste (N=30), LOT: 134524, 141207						
Ageing	None	10,000 Thermal cycling	None	10,000 Thermal cycling	None	10,000 Thermal cycling	None	10,000 Thermal cycling	
Amount	15	15	15	15	15	15	15	15	

Fig. 43: Study design with different veneering methods.[58)]

Thereafter, half of each veneer group was artificially aged by thermocycling (10,000 cycles, 5-55°C, respectively 20 seconds, see Fig. 43).

For subsequent breaking load testing, all samples (including those not artificially aged) were then cemented to conditioned CoCrMo abutments. The abutments of the master cast replaced the canine tooth and the second premolar. Subsequently, the samples of the pontics were loaded with a force of 100 N for 15 minutes. After this breaking load test, the samples were stored for 48 hours in distilled water at 37°C.

The results of the breaking load test show that digitally produced veneers achieve significantly higher breaking load values than the samples of the other three veneering types, regardless of the ageing state of the samples (see Fig. 44, 45). The groups of non-digitally produced veneers achieved breaking load values in a similar range in the test.
The analysis of the break types revealed two typical types of failure: The first three groups (digital and conventional

[57)] See Taufall S, Eichberger M, Schmidlin PR, Stawarczyk B. Fracture load and failure types of different veneered polyetheretherketone fixed dental prostheses. Clinical Oral Investigations 2016;20(9): 2493-2500.
[58)] ibid., Table 1
[59)] ibid., Table 2
[60)] ibid., Table 5
[61)] See Eichberger M, Wimmer T, Stawarczyk B. Are the properties of BioHPP® restorations always the same or does the processing technology have an influence? Investigation of the stability of bridges. The quintessence of dental technology 2014; 40:596.
[62)] See Stawarczyk B, Thrun H, Eichberger M, Roos M, Edelhoff D, Schweiger J, Schmidlin PR. Effect of different surface pretreatments and adhesives on the load-bearing capacity of veneered 3-unit PEEK FDPs. Journal of Prosthetic Dentistry 2015;114(5):666-673.

Framework	breCAM.BioHPP (PEEK), n=120, LOT: 400177							
Veneering	Digital veneering breCAM.HIPC (n=30), LOT: 406700		Conventional veneering crea.lign (n=30), LOT: 130513		Conventional veneering crea.lign Paste (n=30), LOT: 134524, 141207		Prefabricated veneers novo.lign (n=30, LOT: Z3304499, Z3843532, Z3849293, Z3303681	
Ageing	None	10,000 Thermal cycling	None	10,000 Thermal cycling	None	10,000 Thermal cycling	None	10,000 Thermal cycling
Mean [N]	**1882**	**2021**	**1138**	**1008**	**1226**	**1229**	**1213**	**1149**
Average deviation [N]	152	184	278	372	280	239	380	274
95% confidence interval [N]	1797-1967	1919-2124	984-1293	802-1215	1070-1382	1096-1362	1002-1425	997-1301

Fig. 44: The results of the breaking load test show the highest values in digital veneering.[59)]

veneers) showed similar break types and pontic cracks, starting from the connection areas. In the fourth group, the nature of the failure could not be determined optically. However, the load curve showed a failure of the samples and a break was also clearly heard acoustically. The researchers suspected an adhesive failure between the BioHPP® framework and the prefabricated veneers. Overall, all the tested frameworks showed adequate resistance to breakage. 909 N are the maximum for the occlusal force in the posterior region.[61)]

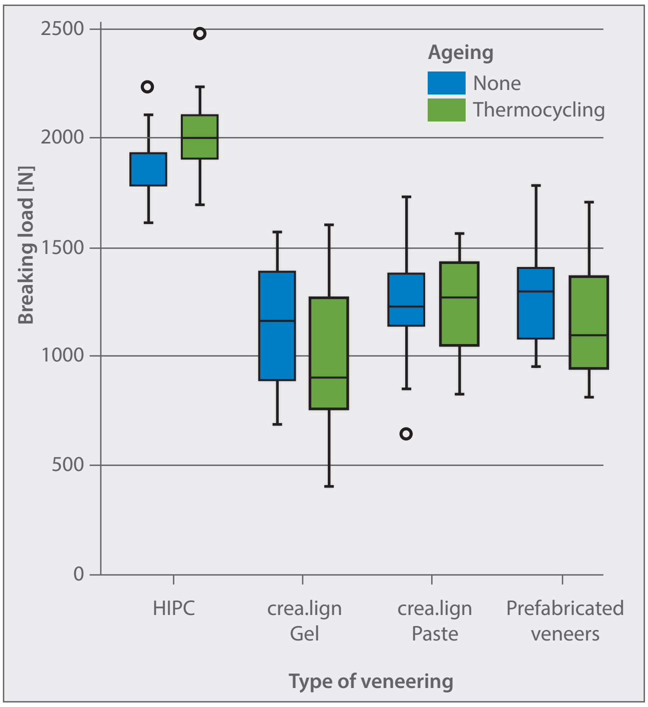


Fig. 45: The results of the breaking load test shown graphically in the box plot diagram.[60)]

The significantly higher breakage resistance values of the digitally produced veneers were explained by researchers with fewer manufacturing steps. In addition, artificial ageing had no noteworthy effect on the load capacity of the samples.
The weak point of the first three veneering groups was the connector area, since the framework here had the lowest strength.
The veneers of the fourth group seemed to have a greater resistance so that the adhesive failed before the veneer could break.
In the present experimental set-up, it should be taken into account that CoCrMo as abutment material has a much higher modulus of elasticity than the hard tooth substance.

Editor's note: "In a previously conducted study of the Ludwig-Maximilians University, the researchers first came to the conclusion that PEEK as a framework material should not be veneered using conventional methods.[62)]
The study presented here was then carried out by the university using the components of the visio.lign® system, thereby demonstrating that BioHPP® frameworks (ceramic-filled PEEK) can be used for veneering. With the visio.lign® system, bredent offers a total of four veneering variants for different indications.

12 Bacterial attachment to BioHPP[63)]

Prof. Dr. J. Geis-Gerstorfer, Dr. L. Scheideler
Eberhard Karls University, Tübingen
Centre for Oral and Maxillofacial Medicine, Department of "Medical Materials Science & Technology"

Adhesion Streptococcus Gordonii (summary)

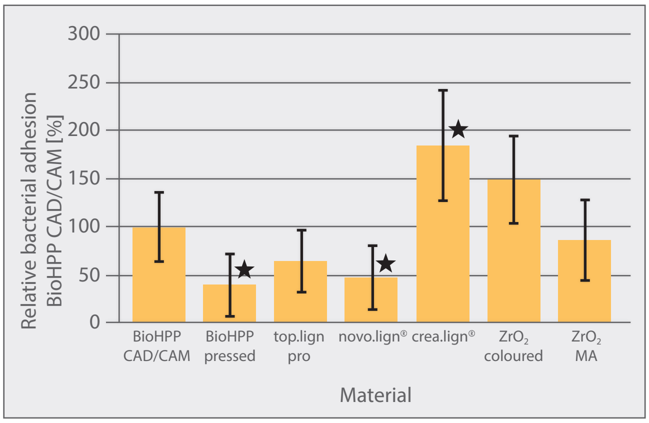
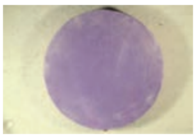
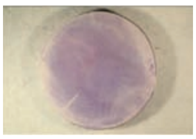


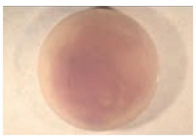
Fig. 46: Initial colonisation by S. gordonii. Summary of data from two trials. Adhesion time: 2 h. (mean values with standard deviations; n = 6; star = significantly different from BioHPP CAD/CAM; p = 0.05).[64)]


BioHPP CAD/CAM
10 x


BioHPP CAD/CAM
32 x


BioHPP pressed 10 x


BioHPP pressed 32 x


top.lign pro 10 x


top.lign pro 32 x


novo.lign® 10 x


novo.lign® 32 x

In the project, the plaque build-up on the PEEK material BioHPP was to be investigated in comparison to other scaffold and veneering materials.

For this purpose, test specimens were exposed to oral bacteria cultures, and the bacterial deposition was optically documented and quantified. In the study, the samples were incubated with different micro-organisms in constant alternation of movement and stagnation. The conditions in the niches of the oral cavity (e.g. interdental spaces) were to be simulated. The experiments were performed with Streptococcus gordonii (as a typical early colonizer of the oral cavity) as well as fresh isolates of mixed oral cultures. Three different dental PMMA-based plastic materials (top.lign, novo.lign, crea.lign) as well as zirconia oxide were used as reference materials. The zirconia oxide was also tested in two different states (ZrO2 colored and ZrO2 CAD/CAM).
The aim of the investigation was to produce surface states that are similar to the real machining state of dental restorations in practice. Accordingly, surface treatment and cleaning were carried out at bredent according to current dental technology methods.

The experiments carried out with different test kits or dyes for bacterial quantification via substrate turnover (metabolic activity) showed some promising approaches but proved to be too insensitive and poorly reproducible in the test system used here. These approaches therefore had to be abandoned after some preliminary tests. The crystal violet staining proved to be the most reproducible detection method despite the problems caused by the surface conditions of the samples in this project.

[63)] See Geis-Gerstorfer J, Scheideler L. Untersuchungen zur initialen Bakterien-Anlagerung an BioHPP im Vergleich zu top.lign pro, novo.lign, crea.lign und Zirkonoxid-Keramik. Tübingen: Eberhard Karls Universität, Medizinische Werkstoffkunde & Technologie; 2015.
[64)] ibid., 6.
[65)] ibid., 7, 8.
[66)] ibid., 9.

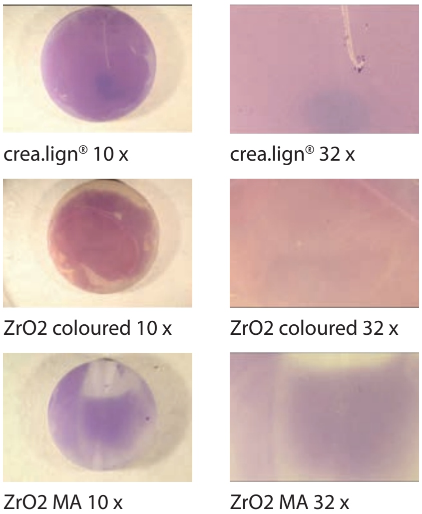


Abb. 47: Results of an experiment to bacteria occupancy with S. gordonii.[65)]

Streptococcus Gordonii Adhesion (metabolic activity CCK-8)

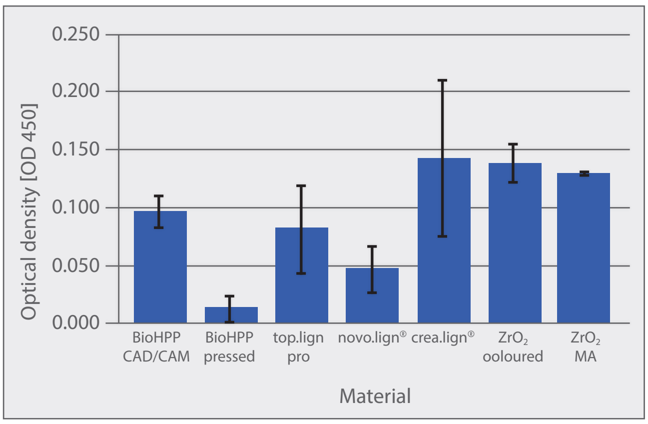


Fig. 48: Initial colonisation by S. gordonii. Metabolic activity test. Adhesion time: 2 h. (mean values with standard deviations; n = 3).[66)]

S. gordonii showed a significantly lower deposition on the surfaces of BioHPP (pressed) and novo.lign compared to the reference surface BioHPP CAD/CAM (Fig. 46). The strongest accumulation on average was measured on the reference plastic crea.lign. Compared with BioHPP CAD/CAM, the detectable amount of adhered bacteria was approximately double that of BioHPP CAD/CAM (184%).

The bacteria were stained with crystal violet. Fig. 47 shows the extent of biofilm formation on the various surfaces by S. gordonii. A typical platelet was documented for each surface. On the left side, an overview image is shown; on the right side, a detailed image is shown It is clearly visible that in the experiments with S. gordonii , the pressed BioHPP surface has a significantly lower occupancy than the CAD/CAM surface. The relatively strong, continuous bacterial coating on crea.lign is also clearly visible in comparison to the novo.lign surface shown above. S. gordonii also showed a relatively pronounced adhesion on the investigated zirconia oxide surfaces.

The results of the CCK-8 assay correlated well with the subsequent crystal violet staining on the same samples. The substrate turnover data (Fig. 48) showed the same trends as the summarized results of bacterial staining by crystal violet (Fig. 46). S. gordonii deposited less on BioHPP (pressed) and novo.lign significantly less than on the reference surface BioHPP CAD/CAM. The strongest accumulation on average was again measured on crea.lign.

Editor's note: "From these results, it can be concluded that exposed BioHPP scaffold geometries in the oral cavity are no more populated with plaque and bacteria than those made of zirconia or veneering composites. This requires a high-gloss polished surface. For rough surfaces, the results may be different".

13 Influence of different surface treatment methods on contact angle and surface roughness[67)]

Dr. Candida R.C. Sturz
Interdisciplinary Department of Oral Surgery
and Implantology, Department
Craniomaxillofacial and plastic surgery
University of Cologne

The aim of this study was to investigate the effects of different processing methods on the surfaces of dental restorative materials.

The researchers measured the surface roughness and hydrophobicity of PEEK (BioHPP®), three plastics (breformance, crea.lign®, novo.lign®) and zirconium dioxide (brezirkon) (see Fig. 49). As a reference, the surface of zircon was used, which was not subjected to any surface treatment (ZrO reference).

Abbreviation	Material	Lot #	Product Name	Filler	Amount of Filler
PEEK-IOF	BioHPP	379805	BioHPP	Inorganic ceramics and metal oxides	<30%
PMMA-noF	PMMA, MMA, EGDMA	374873	breformance	-	-
DMA-nano	Bis-GMA, UDMA, aliphatic dimethacrylates	123765	crea.lign	Inorganic ceramics	~50%
PMMA-DMA	High molecular PMMA and dimethacrylate	3.1/120609	novo.lign	Inorganic ceramics	<10%
ZrO	Yttrium oxide, partially stabilised, isostatically pressed ZrO2	378421	brezirkon	aluminium	0,2–0,5%

Fig. 49: Test materials.[68)]

A total of 160 test specimens were tested, with each material group being polished by four methods:

Group 1: Paper grinding; surface ground with silicon carbide paper, grit 1,000; straight-line grinding movement in one direction

Group 2: Stone grinding; surface evenly ground with cylindrical white Arkansas stone; straight-line grinding movement in one direction with a straight handpiece

Group 3: Air-flow treatment; surface polished with sodium bicarbonate powder (65µm)

Group 4: High-gloss finish; surface polished with bredent diamond paste Zi-polish (1µm) and cotton buff.

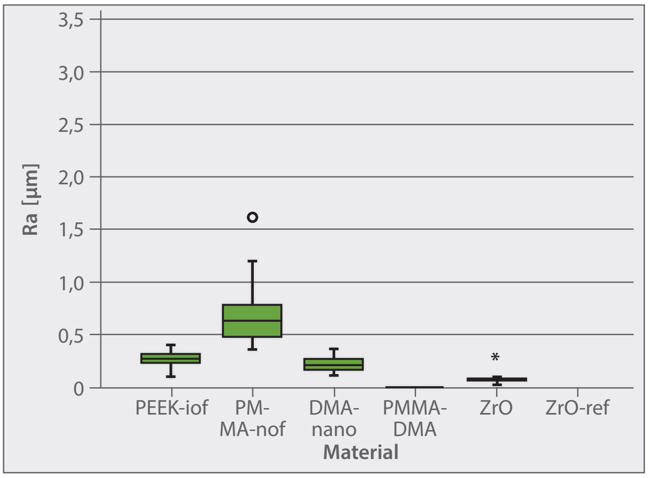
The surface roughness of the samples was determined by the researchers using a laser scanning microscope.

They examined an area of 320x320µm. In determining the hydrophobicity, they measured two contact angles per water drop (left and right).

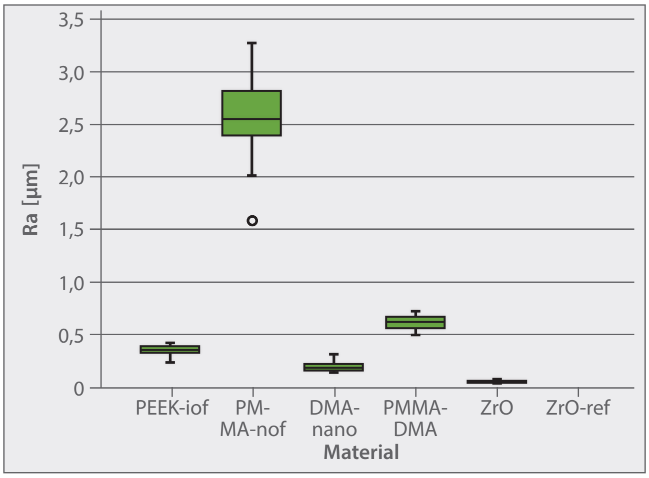
The results of the measurement show that in all material groups there was a significant increase in the surface roughness of all processing methods (see Fig. 50-53). Only with ZrO was the surface roughness significantly reduced. After grinding, PMMA-DMA achieved the lowest Ra value (0.008µm ± 0.0025), while PMMA-noF reached the highest Ra value (2.917µm ± 0.4709) after air-flow treatment. After the air-flow treatment, specifically the surfaces of PMMA-noF and PMMA-DMA were heavily roughened.

[67)] See Sturz CRC, Faber FJ, Scheer M, Rothamel D, Neugebauer J. Effects of various chair-side surface treatment methods on dental restorative materials with respect to contact angles and surface roughness. Dental Materials Journal 2015; 34(6): 796-813.
[68)] ibid., 798
[69)] ibid., 802, 803.
[70)] ibid., 803

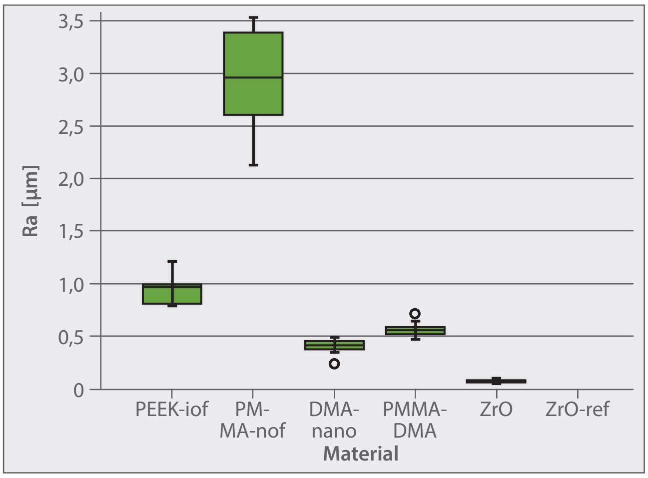
Paper grinding



Stone grinding



Air-flow treatment



High-gloss polishing

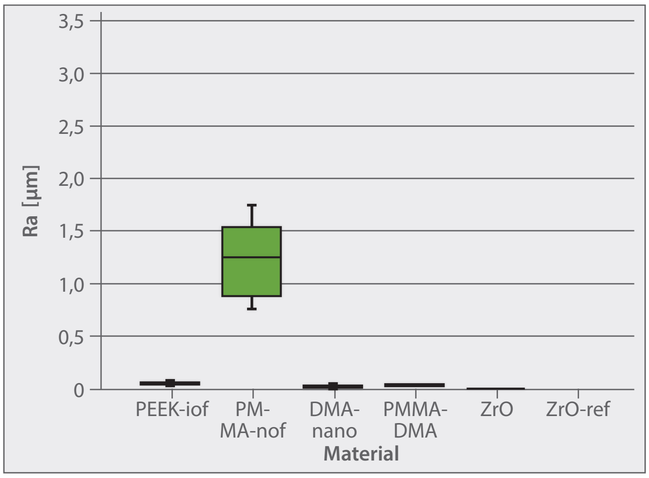
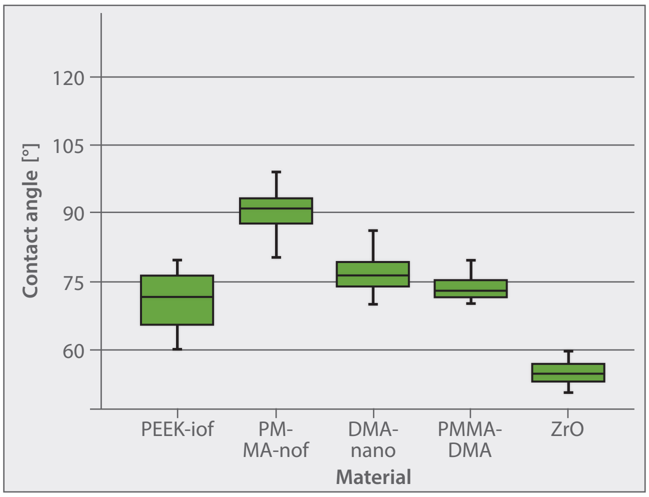


Fig. 50-53: The box plot diagram shows the increase in surface roughness by all machining methods except ZrO.[69]

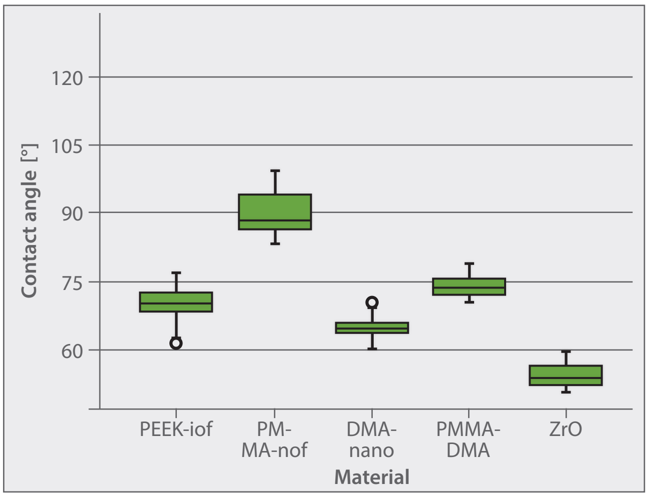
Material	Surface Treatment	Ra Average	SD ±	Rz Average	SD ±	Sa Average	SD ±
PEEK-IOF	Paper grinding	0,277	0,0664	1,589	0,2957	0,547	0,1023
	Stone grinding	0,364	0,0657	1,959	0,1854	1,114	0,1356
	Air-flow treatment	0,952	0,1359	5,613	0,2558	1,505	0,1705
	High-gloss polishing	0,073	0,0128	0,501	0,0448	0,148	0,0384
PMMA-noF	Paper grinding	0,703	0,2867	4,003	1,3486	4,743	1,0355
	Stone grinding	2,567	0,4929	13,050	0,9857	5,103	0,7687
	Air-flow treatment	2,917	0,4709	13,930	1,1547	6,197	0,9268
	High-gloss polishing	1,260	0,3529	6,733	0,7229	3,303	0,6909
DMA-nano	Paper grinding	0,236	0,0727	1,349	0,3917	0,357	0,0712
	Stone grinding	0,218	0,0588	1,261	0,2709	0,907	0,2020
	Air-flow treatment	0,405	0,0742	2,249	0,1588	0,632	0,1852
	High-gloss polishing	0,399	0,0038	0,245	0,0243	0,108	0,0585
PMMA-DMA	Paper grinding	0,008	0,0025	0,800	0,0280	0,020	0,0070
	Stone grinding	0,633	0,0739	3,543	0,3182	1,378	0,3055
	Air-flow treatment	0,567	0,0725	3,200	0,1053	1,076	0,1495
	High-gloss polishing	0,050	0,0064	0,328	0,0255	0,075	0,0117
ZrO	Paper grinding	0,091	0,0449	0,519	0,1299	0,097	0,0243
	Stone grinding	0,073	0,0127	0,419	0,0426	0,106	0,0157
	Air-flow treatment	0,076	0,0148	0,464	0,0954	0,095	0,0088
	High-gloss polishing	0,103	0,0036	0,108	0,0427	0,023	0,0079
ZrO reference		0,058	0,0173	0,352	0,1238	0,073	0,0179

Fig. 54: Results of the surface roughness measurement.[70]

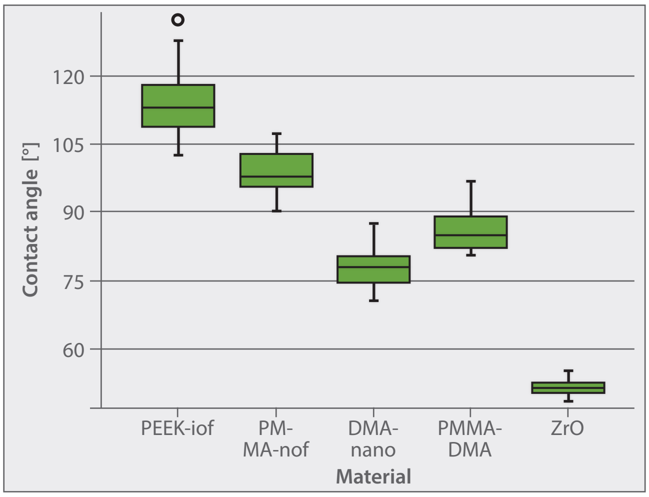
Paper grinding



Stone grinding



Air-flow treatment



High-gloss polishing

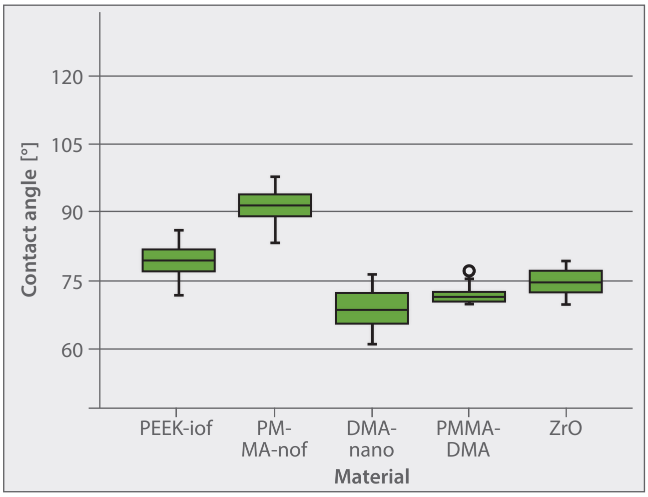


Fig. 55-58: The box plot diagram graphically represents the values of the contact angle measurement.[71)]

The assessment of the contact angle measurement revealed contact angles between 51.6° and 114° (see Fig. 55-58). The ZrO air flow treatment resulted in the lowest contact angle values (51.6° ± 1.16), the highest values were measured with PMMA noF with air flow treatment (114.4 ± 6.46).

[71)] ibid., 808.
[72)] ibid., 808, 809.

Material	Surface Treatment	Average	SD ±
PEEK-IOF	Paper grinding	70,8	5,85
	Stone grinding	70,2	3,35
	Air-flow treatment	114,0	6,46
	High-gloss polishing	79,4	3,57
PMMA-noF	Paper grinding	90,7	4,29
	Stone grinding	90,0	4,90
	Air-flow treatment	98,6	3,91
	High-gloss polishing	91,5	3,46
DMA-nano	Paper grinding	76,9	4,01
	Stone grinding	65,0	2,16
	Air-flow treatment	77,9	4,10
	High-gloss polishing	69,1	4,13
PMMA-DMA	Paper grinding	73,8	2,65
	Stone grinding	73,9	2,47
	Air-flow treatment	86,3	4,96
	High-gloss polishing	71,9	1,55
ZrO	Paper grinding	55,0	2,70
	Stone grinding	54,2	2,45
	Air-flow treatment	51,6	1,61
	High-gloss polishing	75,0	2,63
ZrO reference		94,2	1,18

Fig. 59: Results of contact angle measurement.[72)]

Overall, the largest contact angles in all material groups resulted from the air-flow treatment, except for ZrO. A correlation between the values of the surface roughness and the contact angle could only be clearly demonstrated for the air-flow treatment, all other methods showed no correlation in this regard.
In general, the polishes resulted in a significant increase in the contact angles of PEEK-IOF, PMMA-noF and ZrO. A reduction of the contact angle only caused the polishes in DMA-nano and PMMA-DMA.

Editor's note: "The air-flow treatment and the polish with high-gloss paste also with BioHPP® (PEEK-IOF) resulted in a roughening of the surface, which favours the deposition of plaque and bacteria in the mouth and discoloration. To avoid this effect, BioHPP® should be veneered with the composite crea.lign® (DMA-nano) or with novo.lign® shells. Devices like air flow, for example, should not be used".

14 Study of peri-implant marginal bone loss under immediate loading – Comparison of the fixed complete arch prosthesis with metal structure to the one with polyether ether ketone structure[73)]

Prof. Dr. Dr. Marta Cabo Pastor
Prof. Dr. Dr. Maria Celia Haya Fernández
Department of Dentistry
University CEU Cardenal Herrera,
Valencia

In this in vivo clinical study, 35 patients with a total of 213 implants were immediately treated with a temporary PMMA bridge according to the SKY fast & fixed concept. After 15 to 16 weeks, the final restoration was either a rigid metal composite bridge (Fig. 61 left) or a physiological ceramic-reinforced PEEK composite bridge (Fig. 61 right).

The objective of the study was to determine the degree of bone loss. The peri-implant bone level was measured at three points in time (see Fig. 60): directly after implant placement, after 3–4 months for the final prosthetic restoration, and after 1 year for the recall. The measurement was carried out according to a standardised procedure.

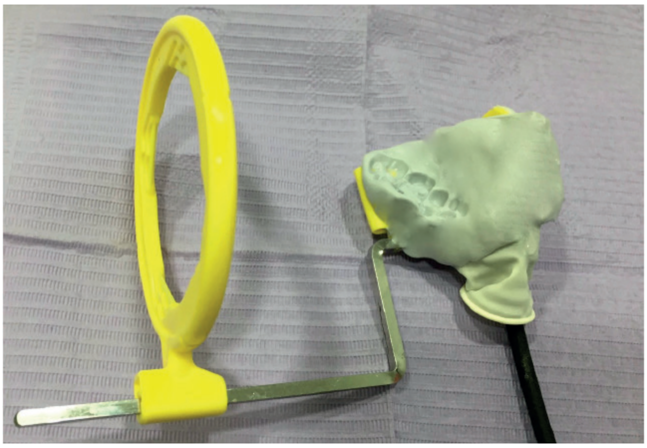


Fig. 60: X-ray probe for measuring bone substance.[74)]

Fig. 61: Implant-supported bridges: left with metal scaffold, right with PEEK scaffold.[75)]

[73)] See Cabo Pastor MB. Estudio de la pérdida ósea marginal periimplantaria en carga inmediata. Comparación de la prótesis fija de arco completo
con estructura metálica o con poliéter éter cetona [Dissertation]. Valencia: Universidad CEU Cardenal Herrera; 2017.
[74)] ibid., 84.
[75)] ibid., 85.
[76)] ibid., 125.

Bone loss per material (with values >0)

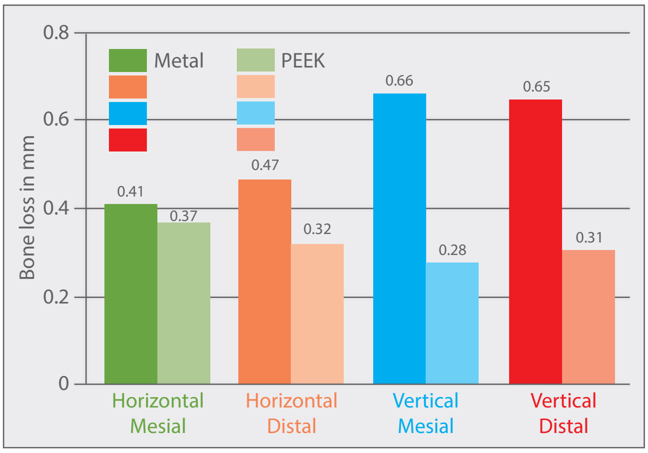


Fig. 62: Bone loss with PEEK prostheses is less than with metal prostheses.[76)]

Treatment with implants guarantees long-term functionality and aesthetics. Sufficient strength of stable bone substance and a suitable gum environment are basic prerequisites for long-term success.

The results of the investigation show that a considerably low bone loss can be observed on the x-ray images when using PEEK. Fig. 62 shows the differences in bone loss in prostheses with metal and PEEK scaffolds.

Editor's note: "The PEEK material tested is BioHPP, a ceramic-reinforced PEEK variant. Because BioHPP is characterised by bone-like elasticity, the force absorption is comparable to that of natural bone. BioHPP can therefore absorb the chewing forces and other loads and does not transfer them directly to the implant".

15 Application of polymer-based abutments for final restorations[77)]

José Eduardo Maté Sánchez de Val
José Luis Calvo-Guirado
International Cathedra of Research
Implantology and Biomaterials
Biomaterials Research Group
University Católica San Antonio de Murcia

Fig. 63: Flapless protocol. (a): Incision with a circular blade. (b) and (c): Detail of the abutment placement.[78)]

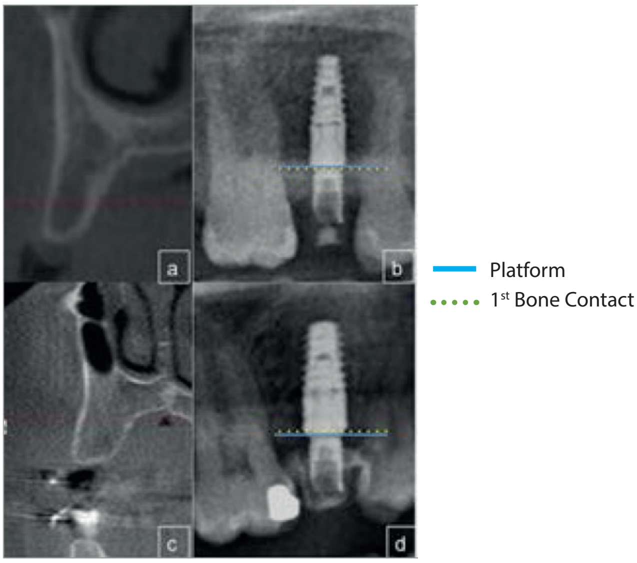


Fig. 64: (a) and (b): Flapless surgical protocol. Previous CT and detail of measurements between the implant platform and the point of first bone contact. (c) and (d): Standard surgical protocol with detail of measurements.[79)]

Uses of PEEK in dentistry are still under development; the material has been mainly employed for implant abutments. The aim of this study was to examine the application of polymer-based abutments for definitive dental restorations through a single protocol connection, using two surgical techniques (standard and flapless).

Traditionally, abutments have been made from biocompatible materials such as titanium and other metal alloys. Other therapeutic options include customized abutments based on ceramics or zirconia. But neither of these is suitable for the one-stage approach in which the implant is immediately restored after placement.

In this study ten blueSKY implants (bredent medical, Senden, Germany) with 3.5 to 4 mm of diameter and 10 to 12 mm of length were randomly crestally placed in the premolar zone (P1 or P2) of the maxillary bone. Furthermore ten BioHPP SKY elegance abutments were connected at the time of implant placement (immediate loading). BioHPP SKY elegance abutments are hybrid abutments in which the abutment body made of BioHPP is connected to the titanium base without gap. These abutments are used in single-stage treatment (immediate restoration), since they combine the properties of a temporary and a definitive abutment, i.e. it is not necessary to change the abutment. All crowns were produced from feldspatic ceramic (IPS Empress CAD Cerec/InLab) using a Cerec system and cemented using self-adhesive Rely-X universal cement.

Radiological analysis
Standardized radiographs were taken on the day of implant placement and at one, three and five months using a paralleling system. The radiological analysis was performed with the ImageJ software (Wayne Rasband, USA). The distances between the platform and the first bone contact were recorded (Fig. 64).

Fig. 64 show previous CT scans (left) of the sample case and radiological analysis after implant placement (right). No bone loss surrounding the implants is observed. A good stability of bone height can be appreciated. Fig. 65 lists length measurements between the implant platforms and the points of first bone contact.

ISQ analysis
Stability measurements were made at baseline to assess the stability of the implant to examine whether immediate loading was feasible. An ISQ value of 65 was defined as a minimum. The ISQ values were obtained using Osstell Mentor (Osstell, Göteborg, Sweden).

	Patient	1 month	3 months	5 months	p-value
Flapless	1	0.02±0.01 (0.02)	0.05±0.25 (0.05)	0.04±0.04 (0.04)	
	2	0.01±0.05 (0.01)	0.17±0.11 (0.17)	0.15±0.10 (0.15)	
	3	0.21±0.13 (0.21)	0.13±0.09 (0.13)	0.09±0.01 (0.09)	
	4	0.43±0.33 (2.33)	0.11±0.19 (0.11)	0.13±0.03 (0.13)	
	5	0.39±0.05 (0.39)	1.12±0.32 (1.12)	0.09±0.11 (0.09)	
	Flapless (mean)	0.21±0.14 (0.21)	0.31±0.04 (a) (0.31)	0.10±0.03 (0.10)	p=0.043
Standard	6	0.31±0.13 (0.31)	1.02±0.39 (1.02)	1.21±0.34 (1.21)	
	7	0.33±0.14 (0.33)	0.98±0.76 (0.98)	1.19±0.38 (1.19)	
	8	0.64±0.63 (4.32)	1.32±0.99 (1.32)	1.23±0.45 (1.23)	
	9	0.39±0.3 (0.39)	1.05±0.33 (1.05)	1.02±0.15 (1.02)	
	10	0.85±0.49 (0.85)	0.99±0.65 (0.99)	1.21±0.47 (1.21)	
	Standard (mean)	0.50±0.41 (b) (3.64)	1.07±1.12 (a) (b) (1.07)	1.17±0.87 (a) (b) (1.17)	(a) p=0.031 (b) p=0.011
	p-value	0.044	0.022	0.017	

Fig. 65: Radiological analysis of samples. The results are presented as mean ± SD (median). A non-parametric Friedman test.[80)]

	Patient	Day 0
Flapless	1	66.43±4.21 (66.43)
	2	69.43±5.42 (69.43)
	3	67.45±3.39 (67.45)
	4	70.03±5.23 (70.03)
	5	65.06±3.97 (65.06)
	Flapless (mean)	67.68±5.10 (67.68)
Standard	6	68.39±6.03 (68.68)
	7	65.63±2.98 (65.63)
	8	66.03±2.64 (66.03)
	9	69.83±5.00 (69.83)
	10	70.63±6.01 (70.63)
	Standard (mean)	68.10±4.93 (68.10)
	p-value	0.063

Fig. 66: ISQ analysis for each patient. The results are presented as mean ± SD (median). Significant differences at $p < 0.05$. Comparison between groups.[81)]

Fig. 66 lists the ISQ values for the implants on the day of placement. All implants showed values above the minimum established for this study (ISQ of 65).

Mucogingival analysis and clinical findings

The bleeding index for the implants was recorded at one, three and five months after implant placement by means of a special peri-implant probing technique. Moreover, any post-insertion loss of periimplant mucosa and any height loss were recorded. Bleeding on probing (0 = none, 1 = present) was also tested for at one, three and five months. Insertion lengths were measured using a conventional plastic probe, with the same investigator taking six measurements for each implant. The results are presented as the means of six measurements.

Fig. 67 lists gingival and bleeding indices for all implants. No implant exhibited retractions or insertion loss. The insertion length is listed in Fig. 68. Greater length was observed in the standard group compared with the flapless group and no significant differences were observed between different times within each group.
No abnormal clinical signs of inflammation were observed at the time of review of the study. There was complete adaptation of the peri-implant soft tissue to the crown and the emergence profile of the BioHPP SKY elegance abutment. With the flapless protocol, the healing process was faster than with the standard protocol, but towards the end it was similar.

[77)] See Sánchez de Val JEM, Calvo-Guirado JL. Klinische und experimentelle Studie eines neuen keramisch verstärkten PEEK-Titan-Hybrid abutments unter Sofortbelastung mit einer Keramikkrone. Verwendung von Abutments auf Polymerbasis für definitive Versorgungen. BDIZ EDI konkret 2015;4:72-79.
[78)] ibid., 78.
[79)] ibid., 76.
[80)] ibid.
[81)] ibid.

	Patient	1 month	3 months	5 months	p-value
Flapless	1	0.23±0.05 (0.23)	0.13±0.05 (0.13)	0.05±0.06 (0.05)	
	2	0.12±0.06 (0.12)	0.10±0.06 (0.10)	0.06±0.07 (0.06)	
	3	0.15±0.07 (0.15)	0.11±0.05 (0.11)	0.02±0.06 (0.02)	
	4	0.24±0.06 (0.23)	0.13±0.07 (0.13)	0.02±0.03 (0.02)	
	5	0.23±0.1 (0.23)	08±0.03 (0.08)	0.05±0.01 (0.05)	
	Flapless (mean)	0.19±0.06 (0.19)	0.11±0.03 (a) (0.11)	0.04±0.03 (b) (0.04)	(a) 0.023 (b) 0.039
Standard	6	0.31±0.16 (0.31)	0.19±0.04 (0.19)	0.09±0.12 (0.09)	
	7	0.33±0.21 (0.33)	0.25±0.14 (0.25)	0.11±0.05 (0.11)	
	8	0.10±0.01 (0.10)	0.11±0.07 (0.11)	0.04±0.01 (0.04)	
	9	0.18±0.11 (0.18)	0.15±0.12 (0.15)	0.09±0.04 (0.09)	
	10	0.16±0.03 (0.16)	0.12±0.11 (0.12)	0.01±0.03 (0.01)	
	Standard (mean)	0.21±0.01 (a) (0.21)	0.16±0.05 (b) (0.17)	0.06±0.02 (0.06)	(a) 0.014 (b) 0.033

Fig. 67: Values for bleeding on probing (0 = none; 1 = present) at one, three and five months. The results are presented as mean ± SD (median).[82]

	Patient	1 month	3 months	5 months	(a) p-value
Flapless	1	2.19±0.22 (2.19)	2.21±0.20 (2.21)	2.26±0,19 (2.26)	
	2	2.24±0.20 (2.24)	2.27±0.23 (2.27)	2.30±0,23 (2.30)	
	3	2.29±0.18 (2.29)	2.31±0.21 (2.31)	2.34±0,20 (2.34)	
	4	2.33±0.28 (2.33)	2.37±0.26 (2.37)	2.40±0,25 (2.40)	
	5	2.19±0.22 (2.19)	2.21±0.20 (2.21)	2.26±0,19 (2.26)	
	Flapless (mean)	2.24±1.84 (2.24)	2.27±0.18 (2.21)	2.31±0,03 (2.31)	
Standard	6	3.41±0.74 (3.41)	4.19±1.03 (4.19)	4.21±0,12 (4.21)	
	7	3.15±1.21 (3.15)	4.11±1.20 (4.11)	44±1,05 (4.44)	
	8	4.32±1.51 (4.32)	4.12±0.13 (4.13)	4.01±1,01 (4.01)	
	9	4.19±1.33 (4.19)	3.32±0.05 (3.32)	3.54±0,09 (3.54)	
	10	3.14±0.94 (3.14)	5.23±0.14 (5.23)	4.39±1,93 (4.39)	
	Standard (mean)	3.64±1.02 (b) (3.64)	4.19±1.05 (a) (b) (4.20)	4.11±1,02 (b) (4.11)	(a) p=0.029
	(b) p-value	0.041	0.013	0.033	

Fig. 68: Insertion lengths in mm at one, three and five months after implant placement. The results are presented as mean ± SD (median). A non-parametric Friedman test was performed. (a) Comparison between times for each technique. (b) Comparison between techniques.[83]

The BioHPP SKY elegance abutment interacts perfectly with the peri-implant tissue, as evidenced by the absence of swelling and faster healing of the soft tissue. This biocompatibility is one of the most evident and appreciated data obtained from this study and from a review of the literature.

Editor's note: "Within the limitations of a clinical pilot study in terms of sample size, it can be concluded that the BioHPP SKY elegance abutment is an ideal solution for those implant cases where immediate loading with a definitive restoration in a single session is performed; it provides high levels of biocompatibility, mechanical and flexural strength and elasticity and achieves highly aesthetic results."

16 In-vivo study: Peri-implant tissues behavior around non-titanium material: Experimental study in dogs[84]

José Eduardo Maté
Sánchez de Val
Carlos Pérez Albacete
Martínez Sergio Gehrke
María P. Ramírez Fernández
Vicente G. Vicent
Gerardo Gómez Moreno
José L. Calvo Guirado
University Católica San Antonio
de Murcia (UCAM)
Biotechnology UCAM Research Center
University of Granada

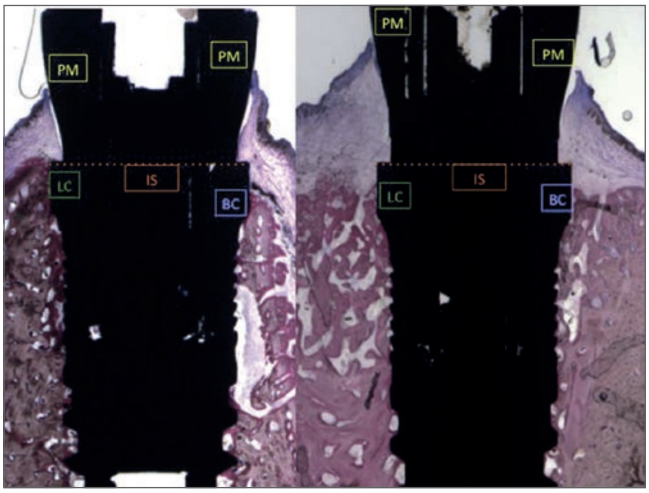


Fig. 69: On the left, the soft tissue is attached to a titanium abutment; on the right, it is attached to a BioHPP abutment. On the right, the higher level of soft tissue is clearly visible lingually.[85]

PM = Peri-implant mucosa
IS = Implant shoulder
LC = Lingual bone crest
BC = Buccal bone crest

Six male American Foxhound of approximately one year of age, each weighing approximately 14–15 kg, were used for this study. Forty-eight tapered dental implants (blueSKY, bredent medical, Senden, Germany) with internal connection and 3.5 mm in diameter and 10 mm length with a collar of 0.7 mm length. All implants were fitted with abutments immediately after placement and divided into two groups. Control group that received 24 titanium abutments and a test group that received 24 PEEK reinforced abutment (SKY elegance, bredent medical, Senden, Germany).

Eight weeks after surgery, all implants showed suitable primary stability. No statistically relevant differences were found between the groups; all implants were osseointegrated. The gaps between the implant and alveolus created by the insertion were filled with bone and absorbed by the alveolar ridge.

In both groups, the formation in the marginal defect zone was accompanied by significant dimensional loss of the bone – both in the delicate buccal region and in the more substantial lingual region.

The test group (reinforced PEEK abutment) showed the best results in soft tissue stabilisation in both lingual and buccal analysis. The radiological examination confirmed the results of the histological analysis at the bone level: In the two groups (titanium and PEEK), a greater loss of buccal bone was observed compared with the lingual bone.

82) ibid., 77.
83) ibid.
84) See Sánchez de Val JEM, Pérez Albacete Martínez C, Gehrke S, Ramírez Fernández MP, Vicent VG, Gómez Moreno G, Calvo Guirado JL. Peri-implant tissues behavior around non-titanium material: Experimental study in dogs. European Association for Osseointegration Congress; 2016 Sept 29–Oct 1.
85) See Sánchez de Val JEM, Pérez Albacete Martínez C, Gehrke S, Ramírez Fernández MP, Vicent VG, Gómez Moreno G, Calvo Guirado JL. Periimplant tissues behavior around non-titanium material: Experimental study in dogs. Annals of Anatomy. 2016;206:106

	Titanium	PEEK	p-value
PM-Bc	2.74 ± 0.41	3.11 ± 0.26*	0.032
	2.74	3.11	
PM-LC	2.91 ± 0.03	3.71 ± 0.18 *	0.008
	2.91	3.71	
PM buccal-IS	2.35 ± 0.87	2.95 ± 0.53 *	0.015
	2.35	2.95	
PM lingual-IS	2.65 ± 0.43	3.57 ± 0.38 *	0.003
	2.65	3.57	
IS-BC	2.04 ± 0.11 *	1.53 ± 0.21	0.011
	2.04	1.53	
IS-LC	1.93 ± 0.14 *	1.41 ± 0.19	0.029
	1.93	1.41	

Fig. 70: Linear measurements in millimeter.[86)]

Abb. 70: PM-Bc: distance from the periimplant mucosa to the buccal bone crest; PM-Lc: distance from the periimplant mucosa to the lingual bone crest; PM bucal-IS: distance from periimplant mucosa to the Implant shoulder in the buccal aspect; PM lingual-IS: distance from periimplant mucosa to the Implant shoulder in the lingual aspect; IS-Bc: distance from the top of the implant shoulder to the first bone to implant contact in the buccal aspect; IS-Lc: distance from the top of the implant shoulder to the lingual bone crest. Values as mean ± Sd and Median. Friedmann non parametric test to related samples. Significant differences with P<0.05.

ISQ Value	Insertion		8 weeks		p-value
	Mean ± Sd	Median	Mean ± Sd	Median	
BioHPP abutment	74.46 ± 4.55	74.46	69.53 ± 0.47	69.53	0.16
Titanium abutment	74.19 ± 4.29	74.19	70.80 ± 0.67	70.80	0.23

Fig. 71: Friedman test of ISQ analysis and measurements at initial day and at 8 weeks. Results as mean and medians. (*) Significant differences, p<0.05.[87)]

BIC (%)	Titanium	PEEK	p-value
Mean ± Sd	61.29 ± 1.45	62.52 ± 4.63	0.32
Median	61.29	62.52	

Fig. 72: Friedman test of BIC values comparison between Titanium and Hybrid PEEK-Ti abutments implants placement at 8 weeks follow-up period. Data shows mean, SD and medians. (*) Significant differences, p<0.05. No differences were found.[88)]

[86)] See Sanchez, Periimplant tissues behavior, EAO Congress 2016.
[87)] ibid.
[88)] ibid.
[89)] ibid.
[90)] ibid.

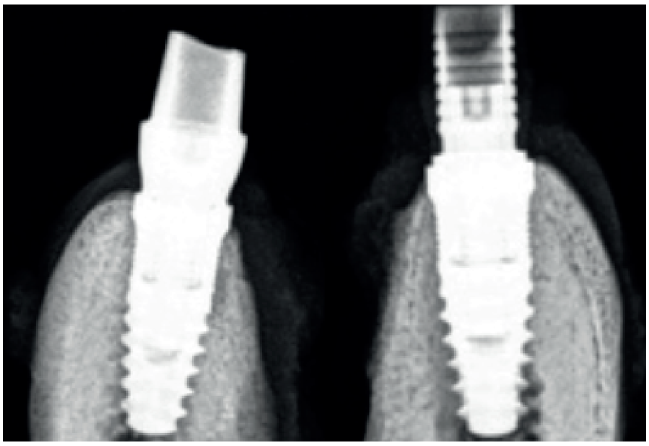


Fig. 73: Radiological picture of the implants with PEEK abutment (left) and Titanium abutment (right).[89]

		Titanium	PEEK	p-value
Buccal bone	Mean ± Sd	1.96 ± 0.21 *	1.43 ± 0.11	0.013
	Median	1.96	1.43	
Lingual bone	Mean ± Sd	1.78 ± 0.33 *	1.28 ± 0.43	0.031
		1.78	1.28	

Fig. 74: Radiological analysis of bone first contact distance to the implant shoulder. Values as Mean ± Sd and Median. Non parametric Friedman test analysis. Significant differences with $p<0.05$.[90]

The application of reinforced titanium peek abutments gives a great aesthetic advantage over other conventional materials; the white color of the abutment allows handling situations involved in fine gingival biotypes without the restrictions of conventional titanium abutments. The materials of high biocompatibility rate, can be used immediately to surgery: "one abutment one time". Quantitative histomorphometric assessment of soft tissue analysis showed that there are differences in favor of peek abutments, with greater height and peri-implant soft tissue thickness, which is important because it implies that there was not peri-implant bone loss and the establishment of biological seal is achieved for the abutment.

Editor's note: "With the limitations of animal experimentation, it can be concluded that the PEEK reinforced with titanium abutments constitute an effective alternative to conventional abutments, given its high rate of biocompatibility and can preserves bone height and soft tissue stability."

Bibliography

1. *Rzanny A, Göbel R, Küpper H.*
   PEEK – ein interessanter Werkstoff und alternatives Gerüstmaterial.
   [PEEK – an interesting material and alternative scaffold material].
   ZWR – Das Deutsche Zahnärzteblatt 2015;123:608-613.

2. *Rzanny A, Göbel R, Fachet M.*
   BioHPP Zusammenfassende Ergebnisse der werkstoffkundlichen Untersuchungen.
   [BioHPP Summary results of material science investigations].
   Jena: Friedrich-Schiller-Universität; 2013.

3. *Faber FJ, Holzer N, Roggendorf H.*
   In-vitro-Untersuchungen mit BioHPP in der Teleskoptechnik.
   [In vitro investigations of BioHPP in telescope technology].
   Köln: Universitätsklinikum, Zentrum für Zahn-, Mund- und Kieferheilkunde; 2013.

4. *Schulte F.*
   Verbundfestigkeit zwischen verschiedenen Polyetheretherketonen und Verblendkunststoffen
   in Abhängigkeit von der Oberflächenvorbehandlung (Dissertation).
   [Composite strength between different polyether ether ketones and veneering resins depending on surface pre-treatment (Dissertation)].
   Universität zu Köln; 2015.

5. *Eichberger M, Wimmer T, Stawarczyk B.*
   Sind die Eigenschaften von BioHPP-Restaurationen immer gleich oder hat die Verarbeitungstechnik einen Einfluss?
   [Are the properties of BioHPP restorations always the same or does the processing technique have an influence?]
   Untersuchung anhand der Stabilität von Brücken. [Are the properties of BioHPP restorations always the same, or does the processing technique have an influence? Investigation based on the stability of bridges].
   Die Quintessenz der Zahntechnik 2014; 40:588-598.

6. *Heimer S.*
   Polierbarkeit und Reinigungsmethoden des Hochleistungswerkstoffes Polyetheretherketon (PEEK) (Dissertation).
   [Polishability and cleaning methods of the high-performance material polyetheretherketone (PEEK)] (Dissertation).
   München: Ludwig-Maximilians-Universität; 2017.

7. *Heimer S.*
   Zwischenergebnisse der Reinigungsstudie des Gerüstwerkstoffes BioHPP.
   [Intermediate results of the cleaning study of the scaffold material BioHPP].
   München: Ludwig-Maximilians-Universität; 2014.

8. *Zylla, IM.*
   Entstehung der Oxidschicht beim Überpressen vorgefertigter Titanabutments mit BioHPP.
   [Formation of the oxide layer when pressing over pre-fabricated titanium abutments with BioHPP].
   Hochschule Osnabrück, Labor für Metallkunde und Werkstoffanalytik; 2014.

9. *Kolbeck C., Rosentritt M.*
   In-vitro-Untersuchung viergliedriger Brücken auf Kunststoffstümpfen (TCML und Bruchtest):
   Vollanatomische Gestaltung aus PEEK gefräst bzw. gepresst.
   [In vitro examination of four-unit bridges on plastic dies (TCML and fracture test): fully anatomical design made of PEEK (milled and pressed)].
   Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2011.

10. *Kolbeck C, Rosentritt M.*
    Versuch zur Überprüfung der Abzugskräfte zwischen Abutment (Titan, BioHPP) und Käppchen (ZrO2, Bio HPP) mit 4°/8° Konuswinkeln zur Verifizierung verschiedener Zemente.
    [Attempt to check the pull-off forces between abutment (titanium, BioHPP) and coping (zirconia dioxide, BioHPP) with 4°/8° cone angle for verification of different cements].
    Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2013.

11. Quick Reference Card für die Zahnarztpraxis.
    - Leitfaden zur Orientierung bei der Anwendung von BioHPP.
    [-Guideline for orientation in the application of BioHPP].
    bredent GmbH & Co. KG, Senden; 2017.

12. *Kolbeck C, Rosentritt M.*
In-vitro-Untersuchung viergliedriger Brücken auf Humanzähnen (TCML und Bruchtest): verschiedene Gerüst-/Verblendmorphologien.
[In vitro examination of four-unit bridges on human teeth (TCML and fracture test): various scaffold/veneer morphologies].
Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2015.

13. *Rosentritt M.*
In-vitro Untersuchung von dreigliedrigen standardisierten Brücken.
[In vitro examination of three-unit standardized bridges].
Universitätsklinikum Regensburg, Poliklinik für Zahnärztliche Prothetik; 2011.

14. *Taufall S, Eichberger M, Schmidlin PR, Stawarczyk B.*
Fracture load and failure types of different veneered polyetheretherketone fixed dental prostheses.
Clinical Oral Investigations 2016;20(9):2493-2500.

15. *Geis-Gerstorfer J, Scheideler L.*
Untersuchungen zur initialen Bakterien-Anlagerung an BioHPP im Vergleich zu top.lign pro, novo.lign, crea.lign und Zirkonoxid-Keramik.
[Investigations on the initial bacterial attachment to BioHPP compared with top.lign pro, novo.lign, crea.lign, and zirconia oxide ceramics].
Tübingen: Eberhard Karls Universität, Zentrum für Zahn-, Mund- u. Kieferheilkunde, Sektion „Medizinische Werkstoffkunde & Technologie“; 2015.

16. *Cabo Pastor MB.*
Estudio de la pérdida ósea marginal periimplantaria en carga inmediata. Comparación de la prótesis fija de arco completo con estructura metálica o con poliéter éter cetona (Dissertation).
[Study of peri-implant marginal bone loss under immediate loading. Comparison of the fixed full arch prosthesis with metal framework or polyether ether ketone] (Dissertation).
Valencia: Universidad CEU Cardenal Herrera; 2017.

17. *Sánchez de Val JEM, Calvo-Guirado JL.*
Klinische und experimentelle Studie eines neuen keramisch verstärkten PEEK-Titan-Hybridabutments unter Sofortbelastung mit einer Keramikkrone. Verwendung von Abutments auf Polymerbasis für definitive Versorgungen.
[Clinical and experimental study of a new ceramic-enforced PEEK-titanium hybrid abutment placed in healed bone with an immediate loading ceramic restoration Application of polymer-based abutments for final restorations].
BDIZ EDI konkret 2015;4:72-79.

18. *Sánchez de Val JEM, Pérez Albacete Martínez C, Gehrke S, Ramírez Fernández MP, Vicent VG, Gómez Moreno G, Calvo Guirado JL.*
Peri-implant tissues behavior around non-titanium material: Experimental study in dogs.
European Association for Osseointegration Congress; 2016 Sept 29–Oct 1.

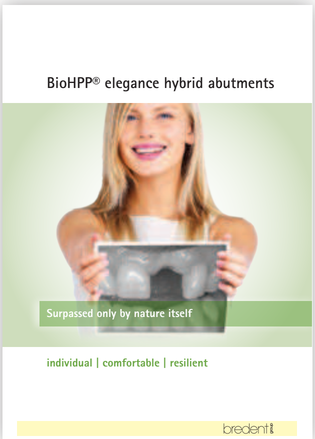
19. *Sanchez de Val JEM, Perez Albacete Martinez C, Gehrke S, Ramirez Fernandez MP, Vicent VG, Gomez Moreno G, Calvo Guirado JL.*
Periimplant tissues behavior around non-titanium material: Experimental study in dogs.
Annals of Anatomy. 2016;206:104-109.

20. *Göbel R, Rzanny A.*
Verbundfestigkeit zwischen verschiedenen Verblend- und Gerüstwerkstoffen. Darstellung werkstoffkundlicher Untersuchungen zur Verbundkombination dentaler Werkstoffe.
[Bond strength between different veneering and framework materials. Demonstration of material science investigations to bond combination of dental materials]
Die Quintessenz der Zahntechnik. 2016;42(8):1064-1068.

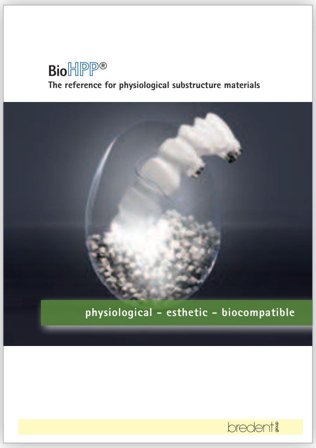
21. *Sturz CRC, Faber FJ, Scheer M, Rothamel D, Neugebauer J.*
Effects of various chair-side surface treatment methods on dental restorative materials with respect to contact angles and surface roughness.
Dental Materials Journal 2015; 34(6): 796-813.

BioHPP® Study Results 2011-2018

Other offers that may be of interest to you:



REF 000534GB



REF 000547GB

REF 000535GB

000588GB-20181123 Mistake and subject to change reserved

bredent GmbH & Co. KG
bredent medical GmbH & Co. KG
Weissenhorner Str. 2 · 89250 Senden · Germany
T: +49 7309 872-441 · www.bredent.com · @: info@bredent.com