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Impact of air-abrasion pressure and adhesive systems on bonding parameters for polyetheretherketone dental restorations

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ABSTRACT

Objectives: To investigate the impact of polyetheretherketone (PEEK) surface modification on tensile bond strength (TBS), acidity parameters (D) and surface properties.
Methods: For TBS, 486 PEEK specimens were fabricated and air-particle abraded with 50 µm Al_2O_3 according to varying pressure: 0.05, 0.2 or 0.4 MPa. Specimens were directly conditioned (n = 18/group): 1. Scotchbond Universal (SBU); 2. Clearfil Universal Bond (CUB); 3. Futurabond U (FBU), 4. Adhese Universal (AU), 5. G-Premio Bond (GPB), 6. Pekk Bond (PB), 7. visio.link (PCG/positive-control-group), 8. without conditioning (NCG/negative-control-group) and luted with Clearfil SA Cement. After thermal cycling (5,000x) TBS was measured. On air-particle abraded PEEK surfaces and different adhesive systems (n = 6/pretreatment) D was analysed by contact angle measurement, surface roughness tactile by profilometer and optical by SEM with 3D-images followed by surface topography, EDX- and XRD-analysis. Data was analysed using 2-/1-way ANOVA, Kruskal-Wallis H-, Mann-Whitney-U-, Kaplan-Meyer-, Chi^2- and Spearman-Rho-test.
Results: PCG followed by SBU and AU showed the highest TBS and survival rates. PB air-particle abraded with 0.4 MPa presented comparable TBS with PCG. NCG and GPB showed lowest TBS. Specimens air-particle abraded with 0.05 MPa presented lower D-values than those with 0.2 or 0.4 MPa. PCG followed by PB showed higher D-values compared to SBU, CUB, FBU, AU and GPB. All air-particle abraded specimens showed embedded Al_2O_3-particles and for 0.2 and 0.4 MPa more roughened surface areas.
Significance: The pressure during air-particle abrasion of PEEK restorations must be matched to the adhesive system. A general recommendation is not possible. Universal adhesives might be an alternative conditioning for cementation of PEEK compared to PCG.

1. Introduction

Polyetheretherketone (PEEK) is one of the mainly used modification of polyaryletherketones (PAEKs) [1]. It is a high performance thermoplastic with outstanding mechanical, chemical and physical properties that has already been in focus of medical science for a couple of years [2,3]. Previous studies showed that PEEK is ideal as implant material due to the good mechanical properties, which are similar to human bone, in combination with its good biocompatibility [4,5]. The ongoing research led to a manifold application of PEEK in dentistry and has recently emphasised the possibility to use PEEK for fixed dental prostheses (FDPs, e.g. crowns, bridges, implant abutments) [6–12] as well as for removable dental prostheses (RDPs, e.g. partial dentures) [10,13,14]. Regarding to the processability, it was established that PEEK has great milling and grinding properties and is well processable using the CAD/CAM-technology [15–18]. Since several factors suggest the application of PEEK for a wide range of indications in dentistry, it was successfully modified using titanium oxide (up to approx. 30 wt%) to improve the mechanical and optical properties.

Besides all the advantageous properties, the inertness of the PEEK surface with its low surface energy and poor wettability limits an effective and durable bonding, which is required for veneering and cementation of FDPs. Therefore, many previous studies focused on different surface modifications of PEEK including etching with sulfuric or piranha acid [19–28], plasma treatments [20,22,25,29], tribochemical treatments using silica-coated alumina particles (Al_2O_3) [6,19,22,30,31] as well as air-particle abrasion with Al_2O_3 [6,19–22,24,25,28,32]. All studies conducted, that surface treatment is

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necessary to improve the wettability in order to achieve adequate bonding to PEEK [6,19,20,23,28,32]. Although, etching with sulfuric acid showed the highest results for bond strength [6,26,32] it is dangerous and thus not suitable for chairside and laboratory applications. A more commonly, adequate and user-friendly PEEK surface modification was the combination between air-particle abrasion using Al_2O_3 and the use of a methyl methacrylate (MMA)-containing adhesive systems [21,23,24,29,33]. In this context, the use of Al_2O_3-particles with different mean sizes (50 and 110 µm) is well investigated [6,19,32]. Most studies air-particle abraded the PEEK surface using Al_2O_3 with a pressure of 0.2 – 0.4 MPa [6,19–22,24,25,28,32]. However, a continuous investigation for the pressure was not found. Knowledge concerning the potential and limitations of PEEK in adhesion to resin composite cements is scarce, if not to say inexistent with regard to the air-particle abrasion pressure. PEEK is a semi-crystalline material with an E-Modulus of 4 GPa [3]. It is conceivable that the pressure influences the bonding properties and can possibly embed the air-abrading particles into the PEEK surface. Therefore, the influence of the air-particle abrasion pressure on the bonding properties and the PEEK surface itself regarding to acidity parameters, surface roughness and surface topography should be focused in combination with the application of chairside adhesive systems. Here, the application of the adhesive system visio.link resulted in highest bond strength properties [21,23,24,29,33]. However, visio.link is a labside bonding material and needs a polymerisation furnace. Thus, it can not be polymerised with conventional chairside LED polymerisation lights. Newly developed universal adhesives, which contain different acidic groups to enable an adhesive bonding to all FDP materials, can be interesting for the conditioning of PEEK. In general, it is desirable to find a reliable chairside method for the surface modification of PEEK that enables the cementation of PEEK restorations and is processable for the dentist easily. Therefore, this study investigated following null hypotheses: i. neither the air-particle abrasion pressure nor the choice of adhesive system shows an impact on the tensile bond strength (TBS) results and acid parameters (D), ii. the air-particle abrasion pressure shows no an impact on the surface roughness and the surface topography.

2. Materials and methods

The investigated PEEK surface modification consisted of a mechanical pretreatment by air-particle abrasion using different pressure in combination with a chemical conditioning using different adhesive systems (Table 1a). The impact on TBS with fracture types and D was investigated. Additionally, surface properties were analysed for the differently air-particle abraded PEEK surfaces.

2.1. TBS and fracture type analysis

Four hundred and eighty six PEEK specimens (Dentokeep, nt-trading, Karlsruhe, Germany Lot No.11DK14001) with a surface area of approximately 16 mm^2 were cut with a handpiece (KaVo EWL K9, KaVo Dental GmbH, Biberach/Riß, Germany) under dry conditions and embedded in acrylic resin (ScandiQuick A and B, ScanDia, Hagen, Germany, Lot No.09201 and 09202). The specimens were polished up to P1200 (SiC Foil, Struers) for 20 s with an automatic polishing device (Tegramin 20, Struers) under permanent water cooling.

The specimens were divided into 3 groups ($n = 162$) according to the air-particle abrasion pressure: i. 0.05 MPa, ii. 0.2 MPa, iii. 0.4 MPa. All specimens were air-particle abraded (basis Quattro IS, Renfert, Hilzingen, Germany) using Al_2O_3 with a mean particle size of 50 µm (Orbis Dental, Münster, Germany) for 10 s, at 45 ° angle and a distance of 10 mm between the nozzle with an inner diameter of 1 mm and the PEEK surface. Subsequently, all specimens were ultrasonically cleaned (L & R Transistor/Ultrasonic T-14, L & R, Kearny, NJ, USA) in distilled water for 60 s and air-dried. The pretreatment was directly performed before conditioning and luting of the specimens.

Then, the specimens were divided into 8 subgroups ($n = 18$): (1) Scotchbond Universal (SBU; 3 M, Seefeld, Germany), (2) Clearfil Universal Bond (CUB; Kuarary Medical Inc. Sakazu, Kurashiki, Japan), (3) Futurabond U (FBU; Voco GmbH, Cuxhaven, Germany), (4) Adhese Universal (AU; Ivoclar Vivadent, Schaan, Liechtenstein), (5) G-Premio Bond (GPB; GC Europe, Leuven, Belgium), (6) Pekk Bond (PB; anaxDENT GmbH, Stuttgart, Germany), (7) visio.link (PCG; bredent, Senden, Germany) as positive control group and (8) without conditioning as negative control group (Table 1a).

All adhesive systems (except PCG) were applied for 5 s onto the specimen surface using a micro brush and polymerised for 10 s with a distance of 5 mm to the PEEK surface using a LED light unit (Elipar S10, 3 M) with a wavelength of 430–480 nm and a light intensity of 1250 mW/cm^2 (Bluephase Meter II, Ivoclar Vivadent). PCG was applied for 5 s and polymerised for 90 s (bre.Lux Power Unit, bredent, Senden, Germany) with a wavelength of 370–500 nm and a light intensity of 220 mW/cm^2 as recommended by the manufacturer. Afterwards, an acrylic cylinder (SD Mechatronik, Feldkrichen-Westerham, Germany) with an inner diameter of 2.9 mm was positioned on the conditioned PEEK surface, filled with a self-adhesive resin cement Clearfil SA Cement (Kuraray Medical Inc. Sakazu, Kurashiki, Japan) and polymerised for 20 s using the LED light unit. Subsequently, all specimens were stored in distilled water at 37 °C for 24 h (HeraCee 150, Heraeus, Hanau, Germany) and aged by thermal cycling for 5000 cycles between 5 and 55 °C with a dwell time of 20 s in distilled water (Thermocycler THE 1100, SD Mechatronik).

The specimens were positioned in the jig of the testing machine with the PEEK surface perpendicular to the tensile stress which was applied until fracture of each specimen. TBS was measured at a crosshead speed of 5 mm/min (Zwick 1445 RetroLine, Zwick, Ulm, Germany) and calculated as follows: fracture load/bonding area (N/mm^2 = MPa).

To analyse the fracture type, the debonded area of each specimen

Table 1a
Summary of used adhesive systems according to product name, manufacturer, compositions and Lot No.

Product name	Abbrev.	Manufacturer	Composition	Lot No.
Scotchbond Universal	SBU	3 M, Seefeld, Germany	DMA, DMAEMA, EDB, HEMA, MDP	521215
Clearfil Universal Bond	CUB	Kuraray Medical Inc, Sakazu, Kurashiki, Okayama, Japan	bis-GMA, DMA, HEMA, MDP	9M0019
Futurabond U	FBU	Voco, Cuxhaven, Germany	bis-GMA, HDDMA, HEMA, UDMA	1547318
Adhese Universal	AU	Ivoclar Vivadent, Schaan, Liechtenstein	bis-GMA, DMA, DMAEMA, HEMA, methacrylated phosphoric acid ester	U52628
G-Premio Bond	GPB	GC Europe, Leuven, Belgium	DMA, MDP, 2-hydroxy-1,3-dimethacryloxypropan	1602041
Pekk Bond	PB	anaxdent GmbH, Stuttgart, Germany	MMA, UDMA	2016001423
visio.link	PCG	bredent GmbH & Co. KG, Senden, Germany	DMA, MMA, PETIA	135071

bis-GMA – bisphenol-A diglycidyl ether dimethacrylate, DMA – dimethacrylate, DMAEMA – 2-dimethylaminoethyl methacrylate, EDB – ethyl 4-(dimethylamino)benzoate, HEMA – 2-hydroxyethylmethacrylate, HDDMA – hexanedioldimethacrylate, MDP – 10-methacryloyloxydecyl-dihydrogenphosphat, MMA – methyl methacrylate, TEGDMA – triethylenglycol dimethacrlyate, UDMA – urethane dimethacrlyate.