

Effect of Different Adhesive Resin and Composite Veneering Materials on Adhesion to Polyetheretherketone

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Objective: To evaluate the effect of different adhesives and veneering resins on the shear bond strength (SBS) of polyetheretherketone (PEEK).

Methods: A total of 138 PEEK specimens were randomly divided into 6 groups according to adhesive material application: Control (C, no application), Adhese Universal (A) (Ivoclar Vivadent, Schaan, Liechtenstein), Gluma Bond Universal (G) (Heraeus Kulzer, South Bend, IN, USA), G-PremioBOND (P) (GC Corporation, Tokyo, Japan), Single Bond Universal (S) (3M, Saint Paul, MN, USA) and visio.link (V) (Bredent, Senden, Germany). Each adhesive group was divided into two subgroups according to the type of veneering material: Estenia direct composite (D) and Gradia Plus indirect composite (IN) (both GC Corporation). After the veneering process, the specimens were aged by thermal cycling. Kruskal-Wallis and Mann-Whitney U tests were used for SBS analysis ($P < 0.05$).

Results: The highest SBS results were obtained in the V_{IN} group, followed by the V_D , P_D , G_{IN} , A_{IN} , A_D , S_{IN} , S_D , P_{IN} , G_D , C_{IN} and C_D groups, respectively ($P = 0.001$). There were no significant differences in terms of the type of veneering composite when the same adhesive was applied ($P > 0.05$), except for Gluma Bond Universal ($P = 0.009$). All the adhesives tested showed clinically acceptable SBS results.

Conclusion: Visio.link offered the highest adhesion to PEEK, whereas the tested universal adhesives may be used as an alternative to visio.link in clinical settings. It was determined that changing the veneer type has no statistical difference when the same adhesive material is used.

Keywords: composite resin, polyetheretherketone, shear bond strength, universal adhesives
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Polyetheretherketone (PEEK) is a thermoplastic polymer that is frequently used in dentistry for implant restorations and removable and fixed prostheses because of its superior chemical, thermal and mechanical properties and its biocompatibility.^{1–4} Compared to other thermoplastic polymers, it offers many advantages such as less water absorption, high dimensional stability, high polishing properties, low plaque affinity, good wear resistance and low elastic modulus. It acts as a

stress breaker, eliminating the possibility of an allergic reaction.^{2,5}

Despite their advantages, PEEK materials have a greyish-brown or pearly white opaque colour that may not meet clients' aesthetic expectations.^{6–8} To solve this problem, PEEK restoration surfaces can be veneered with composite resins using direct and indirect methods.^{7,8} Indirect composite resins are frequently employed in veneering applications due to their low elastic modulus (8 to 10 GPa), acting as a stress breaker and reducing occlusal stresses, as well as their superior bonding performance, mechanical properties, wide colour range, easy manipulation and reparability.^{9,10} However, in cases where aesthetic expectations cannot be met with indirect veneering or in cases requiring intraoral repair (especially in restorations that cannot be removed from the tooth or implant surface), direct composites are also used instead of indirect composites. Micro-filled direct composite resins

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offer a significant advantage in cases where aesthetic requirements are at the forefront in terms of providing a smooth surface and superior gloss, and they can replace traditional direct composite resins in terms of improving aesthetics.¹¹ Nevertheless, direct or indirect veneering methods do not provide sufficiently strong adhesion to the PEEK surface. This is considered the most significant clinical disadvantage of PEEK materials.^{1,6,10,11} To achieve a strong bond between the resins and PEEK materials, the PEEK surface can be activated with surface treatment protocols before applying the adhesive material.^{1,6,12-16}

Researchers have investigated surface treatment protocols, such as laser treatment, air-abrasion, application of piranha solution or sulfuric acid, and coating the surface with silica or plasma.^{1,3,6,7,13,17} However, with all these surface treatment protocols, adhesive materials are still needed to form a strong bond between the resins and the PEEK materials.^{6,13,18-21} Some studies have determined that visio.link material (Bredent, Senden, Germany) provides the highest SBS^{18,22,23}, but is suitable only for use in a laboratory and not for chairside application because it requires a special polymerisation furnace for application. To overcome these disadvantages, some researchers have proposed using universal adhesive materials and traditional light-emitting diode (LED) polymerisation to increase adhesion with PEEK materials.^{8,20,23}

There is still insufficient information about the success achieved using adhesive materials and different veneering protocols to increase adhesion to PEEK materials.^{1,3,6,8,18,22,23} Thus, the aim of the present study was to evaluate the effect of using different adhesives and resin veneers on the SBS of PEEK materials. The null hypothesis was that conditioning the PEEK surface with different adhesive materials and applying different composite resins as veneers would not affect the SBS of the PEEK materials.

Materials and methods

The study was approved by the Medical Ethics Committee of Pamukkale University, Denizli, Turkey (approval no. 60116787-020/54316 and 60116787-020/328868). The sample size for the study was calculated using G*Power software (version 3.1.9.2; Heinrich Heine Universität, Düsseldorf, Germany). It stipulated 12 independent groups according to an effect size of 0.4, 80% power and 0.05 sampling error.

A total of 138 PEEK specimens (CoproPeek Light; PEEK [≈ 80%], titanium dioxide [< 20%] and other additives [< 0.1%], Whitepeaks Dental Solutions, Wesel,

Germany) were fabricated using CAD/CAM technology according to ISO standard 10477. They were 10 × 10 × 2 mm in size. All the specimens were then embedded in chemically polymerised acrylic resin (Meliodent, Heraeus Kulzer, South Bend, IN, USA), and ground with 200-, 500-, 800- and 1000-grit silicon carbide abrasive papers (FEPA, Struers, Glasgow, UK) under continuous water cooling using an automatic polishing tool (Mecapol P 230, Press, Grenoble, France) at 180 rpm and for 1 minute at each step. Then, the surfaces of all the specimens were air-abraded from 10 mm away with 110 μm Al₂O₃ (Renfert Basic Classic, Renfert, Hilzingen, Germany) at 0.2 MPa at a 45-degree angle for 15 seconds. After the air-abrasion process, all specimens were cleaned in 70% isopropanol in an ultrasonic cleaner (Eurosonic Energy, Euronda, Vincenza, Italy) for 15 minutes, washed with distilled water for 10 minutes and dried under light pressure using an air spray.

All specimens were randomly divided into 6 groups (n = 23) according to the adhesive material applied to them: Control (C), Adhese Universal (A) (Ivoclar Vivadent, Schaan, Liechtenstein), Gluma Bond Universal (G) (Heraeus Kulzer, G-PremioBOND (P) (GC Corporation, Tokyo, Japan), Single Bond Universal (S) (3M, Saint Paul, MN, USA) and visio.link (V) (Bredent). All adhesive materials were used according to the manufacturers' instructions, and all application procedures were completed by the same researcher (SCS). The protocols for applying the adhesive materials are summarised in Table 1.

Subsequently, three specimens from each adhesive material group were randomly selected for analysis through scanning electron microscope (SEM) and elemental change analysis by energy-dispersive x-ray spectroscopy (EDS). For SEM analysis, all the surfaces of the specimens were coated with 80% gold and 20% palladium using a sputtered device (Q150R ES, Quorum Technologies, Laughton, UK). They were evaluated using the original 1000× magnification at 20 kV. The quantitative analysis of the elements on the specimens' surfaces was determined by EDS analysis at 20 kV.

For the SBS analysis, 20 specimens in each adhesive material group were randomly divided into 2 subgroups (n = 10 each) according to the type of veneer material: Estenia (GC Corporation) for the direct veneer group (D), and Gradia Plus (GC Corporation) for the indirect veneer group (IN) (Table 1). The result was twelve study groups using six different adhesive materials and two different composite resins:

- C_D/C_{IN}: Direct/indirect veneering control groups (no adhesive material application);

Table 1 Materials and equipment used in bonding and veneering protocols.

Product	Composition*	Application recommendation*	Manufacturer
Adhese Universal (VivaPen)	10-MDP, 2-HEMA, BisGMA, MCAP, D3MA, highly dispersed silica, ethanol, water, photo initiators and stabilisers. pH 2.8	Apply the product to the material surface with a brush for at least 20 s, disperse the material with oil- and moisture-free compressed air until a glossy, immobile film layer results. Then, perform light application with a light curing device (LED-C, Guilin Woodpecker, Guilin, China) for 10 s at a light intensity of 500–1,400 mW/cm ² for polymerisation	Ivoclar Vivadent,
Gluma Bond Universal	4-META, MDP, methacrylate, acetone, water. pH 1.6–1.8	Apply the product to the material surface with a brush for 20 s gently, dry with a gentle oil-free air flow until the adhesive film no longer moves. Then perform light application for 10 s with a light curing device (LED-C) at a light intensity of > 500 mW/cm ² for polymerisation	Heraeus Kulzer
G-Premio BOND	MDP, 4-MET, MEPS, methacrylate monomer, acetone, water, initiator, silica, pH 1.5	After shaking the bottle, apply the product to the material surface with a brush for 10 s, then dry thoroughly for 5 s with oil-free air. Then, perform light application for 10 s using a light curing device (LED-C) at a light intensity of 700 mW/cm ² for polymerisation	GC Corporation
Single Bond Universal	MDP monomer, dimethacrylate resins, HEMA, vitrebond copolymer, filler, ethanol, water, initiator, silane. pH 2.7	Apply the product to the material surface with a brush and rub it in for 20 s, direct a gentle stream of air over the liquid for about 5 s directed, and light-cured for 10 s with a light-curing device (LED-C)	3M
visio.link	MMA, 2-prepenoic acid reaction products with pentaerythritol, diphenyl (2,4,6-trimethylbenzoyl)-phosphine oxide	Apply the product to the material surface with a brush thinly and only once. Then immediately 90 s of light application with a dental laboratory polymerisation device (GC Labolight Duo, GC Corporation) at 370–400 nm wavelength range	Bredent
Essentia Direct Composite (micro-hybrid)	UTMA, other methacrylate monomers, inorganic filler (92.3%; SiO ₂ , BaO, Al ₂ O ₃ , La ₂ O ₃)	20 s light application with 700 mW/cm ² light intensity curing device (LED-C)	GC Corporation
Gradia Plus Laboratory Composite (nano-hybrid)	1%–5% Bis-GMA, 5%–10% TEGDMA, 1%–5% UDMA, ceramic filler	3 min light application in full-mode with a dental laboratory polymerisation unit (GC Labolight Duo)	GC Corporation

*Material contents are presented according to the manufacturer's information. Al, aluminium; BisGMA, Bisphenol-A glycidyl dimethacrylate; C, carbon; D3MA, Decandiol dimethacrylate; HEMA, hydroxyethyl methacrylate; MCAP, methacrylated carboxylic acid polymer; MDP, methacryloyloxydecyl dihydrogen phosphate; MEPS, methacryloyloxyalkyl thiophosphate methylmethacrylate, MET, methacryloyloxyethyl trimellitate; META, methacryloyloxyethyl trimellitate anhydride; MMA, methyl methacrylate; O, oxygen; Si, silicon; TEGDMA, triethyleneglycol-dimethacrylate; Ti, titanium; UDMA, urethane dimethacrylate; UTMA, urethane tetramethacrylate.

- A_D/A_{IN}: Adhese Universal direct/indirect veneering groups;
- G_D/G_{IN}: Gluma Bond Universal direct/indirect veneering groups;
- P_D/P_{IN}: G-Premio BOND direct/indirect veneering groups;
- S_D/S_{IN}: Single Bond Universal direct/indirect veneering groups;
- V_D/V_{IN}: visio.link direct/indirect veneering groups.

The veneering composite resins were applied by the same researcher (SCS) to the PEEK surfaces treated

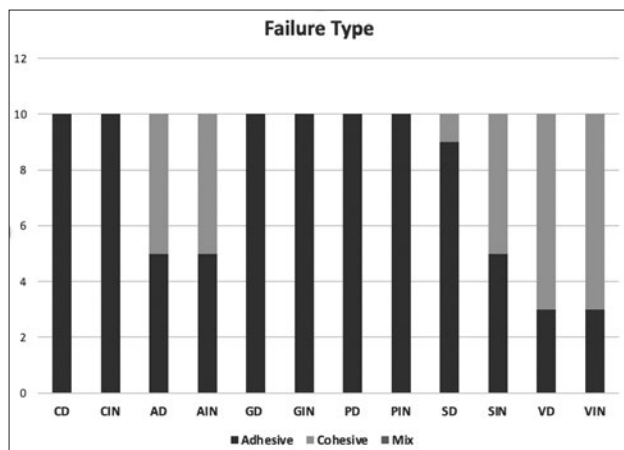
with different adhesive materials using a 2-mm diameter and 3-mm-high disc-shaped silicone mould. The mould was removed after each composite resin was polymerised according to the manufacturer's instructions. The calibration of the light-curing device was checked with a radiometer (Bluephase Meter II, Ivoclar Vivadent, Schaan, Liechtenstein) after every 10 samples throughout the polymerisation procedure. Information about the composition of the resins and the application protocols is summarised in Table 1. After the veneering procedure was completed, the specimens were kept in distilled water for 1 day at room temperature in a dark

Table 2 SBS data according to the different adhesive materials and veneering composite resin materials.

Group (n = 10)	SBS (MPa)		P value*
	Mean ± SD	Min-max (median)	
C _D	12.54 ± 4.90	3.23–17.48 (13.86) ^{a,c}	0.001
C _{IN}	17.29 ± 4.18	12.33–25.62 (16.43) ^{a,b,c}	
A _D	58.38 ± 20.05	30.47–98.5 (52.86) ^{b,e,f}	
A _{IN}	57.73 ± 18.82	31.63–99.41 (54.19) ^{b,d}	
G _D	22.63 ± 12.93	7.88–47.47 (21.89) ^c	
G _{IN}	56.23 ± 11.35	30.44–69.14 (58.56) ^{b,d}	
P _D	62.19 ± 15.02	37.83–80.99 (60.83) ^{d,f}	
P _{IN}	31.1 ± 12.94	2.71–45.29 (31.40) ^{a,b,c,f}	
S _D	50.76 ± 15.75	25.23–78.19 (49.96) ^{a,b,c,d,e}	
S _{IN}	56.91 ± 25.08	28.04–102.18 (52.02) ^{a,b,d,e}	
V _D	89.62 ± 30.36	63.65–164.50 (77.56) ^{d,f}	
V _{IN}	103.85 ± 36.33	72.6–186.05 (94.43) ^{d,f}	

*Kruskal-Wallis test and Mann-Whitney U test with pairwise analysis: $P < 0.05$ and $P < 0.001$. There was no statistically significant difference between the adhesive materials and veneering composite resin materials represented by the same letters, but a statistically significant difference was found between the groups with different letters.

SD, standard deviation.

**Fig 1** Failure distribution of specimens.

environment, then aged by thermal cycling for 5000 cycles between 5°C and 55°C with a dwell time of 20 seconds in distilled water in an automated thermocycling machine (Gökceler Machines, Sivas, Turkey).

A universal test machine (Autograph AGS X; Shimadzu Co, Kyoto, Japan) was used for the SBS test at a crosshead speed of 1 mm/minute. The SBS values were calculated in megapascals (MPa) by dividing failure load (N) by the area of the composite resin ($a = P/A$). The failure types of all the specimens were analysed using an optical microscope (MP 320; Carl Zeiss, Oberkochen, Germany) at 50× magnification. They were categorised as adhesive (failure at the interface between PEEK and the composite resin veneer), cohesive (failure in the PEEK material or the composite resin) and mixed (adhesive and cohesive failure of at least 25% of the surface).

SPSS for Windows version 21.0 (IBM, Armonk, NY, USA) was employed for statistical analysis. The normal distribution of the data was evaluated using a Kolmogorov-Smirnov test. Since the data were not normally distributed, a Kruskal-Wallis test was used to analyse the differences between SBS data according to the different adhesive materials and the composite resins. A Mann-Whitney U test was used for pairwise comparisons of groups with significant differences. Significance was evaluated as $P < 0.05$ and $P < 0.001$.

Results

The highest SBS results were obtained in the V_{IN} group, followed by the V_D, P_D, G_{IN}, A_{IN}, A_D, S_{IN}, S_D, P_{IN}, G_D, C_{IN} and C_D groups. Statistically significant differences were observed between the groups ($P = 0.001$). The types of composite resin for the same adhesive system did not have a significant impact on the results ($P > 0.05$), except for Gluma Bond Universal adhesive (Table 2). There was a statistically significant difference between the G_D and G_{IN} groups in this respect ($P = 0.009$; $P < 0.05$).

Regardless of the type of composite resin, when the control group was compared with the other groups, the C_D group had statistically lower SBS values compared to the A_{IN} ($P = 0.044$), A_D ($P = 0.039$), G_{IN} ($P = 0.04$), P_D ($P = 0.006$), V_D ($P = 0.001$) and V_{IN} ($P = 0.001$) groups. The C_{IN} group had statistically lower SBS values compared to the V_{IN} ($P = 0.001$), V_D ($P = 0.001$) and P_D ($P = 0.044$) groups. In addition, the P_{IN} group had a statistically significant difference only with the V_D ($P = 0.001$) and V_{IN} ($P = 0.002$) groups, which presented the highest SBS values (Table 2). The G_D group with the lowest SBS data

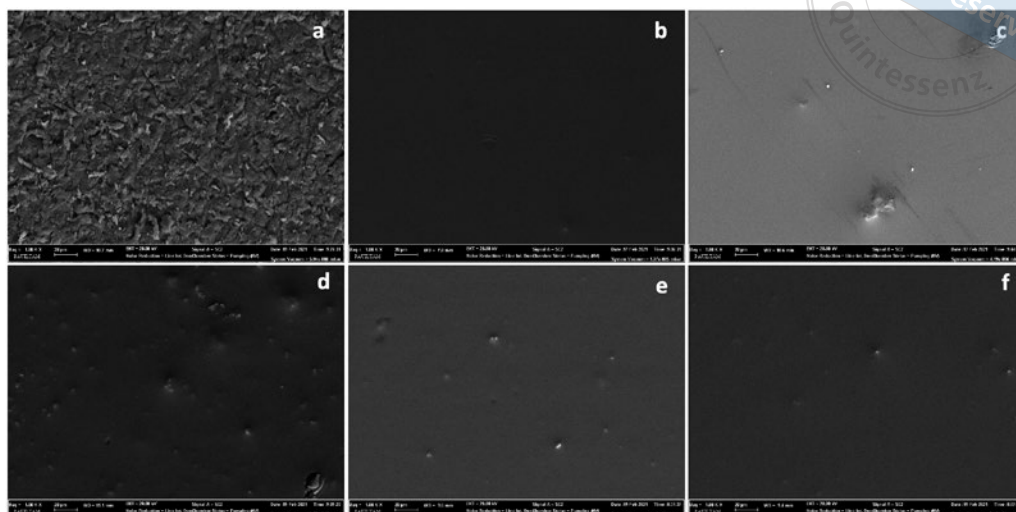


Fig 2 SEM imaging findings at 1000x magnification of PEEK materials after the adhesive material application. Control group, C (a); Adhese Universal group, A (b); Gluma Bond Universal group, G (c); G-Premio BOND group, P (d); Single Bond Universal group, S (e); Visio.link group, V (f).

had the highest statistical difference among the adhesive groups. Accordingly, there was a significant difference between the G_D group and the S_{IN} ($P = 0.018$), A_{IN} ($P = 0.01$), A_D ($P = 0.008$), G_{IN} ($P = 0.009$), P_D ($P = 0.001$), V_{IN} ($P = 0.001$) and V_D ($P = 0.001$) groups (Table 2).

Adhesive failure was detected in the C_{IN} , C_D , P_{IN} , P_D , G_{IN} and G_D groups, whereas both adhesive and cohesive failure were observed in the other groups. No mixed failure was found in any of the study groups (Fig 1).

SEM images of the specimens' surface topography after application of the adhesive material are shown in Fig 2. The surface of the C group had dense microporous areas, and there were differences between the groups regarding the surface covering of the adhesive material. The coverage was more homogeneous in group A (Fig 2b), and some porous areas could still be seen, especially in group P (Fig 2d).

The quantitative data of the elements detected by EDS analysis of the specimen surfaces are presented in Table 3. The elements most detected were C, O, Si and Ti. The most C was found in group A, the most O in group G, the most Ti in group C and the most Si in groups S and V. Moreover, Al was found in the C and P adhesive material groups (Table 3).

Discussion

This study evaluated the effect of different adhesives and composite resin veneers on the SBS of PEEK materials. The results showed that different adhesives and resins affected SBS. Thus, the null hypothesis, namely that the conditioning of the PEEK surface with different adhesives and the application of different composite resin veneers would not affect the SBS of the PEEK materials, was rejected.

The characteristic of the adherent surface is one of the most important parameters in adhesive applications. For this reason, a wide variety of surface pretreatments have been applied to improve the surface properties of polymeric materials and increase the adhesion of the surface area.¹⁵ Air-abrasion is one of the simplest pretreatment methods to increase surface roughness. The adhesion surface area is expanded, organic pollutants are removed from the material surface and an active surface layer is formed.^{14,24} Because of this, airborne-particle abrasion was the preferred surface pretreatment process in the present study.

Pretreatment modulates the PEEK surface to strengthen the micromechanical bond of the resin-containing materials; however, the use of adhesive systems is essential to establish a strong bond between the PEEK and the resin-containing materials. The SBS is related to the content of the adhesive materials.⁶ Many studies have shown that adhesive materials containing methyl methacrylate (MMA) monomers exhibit greater SBS between resins and PEEK materials.^{8,15,18,22,24} Among the adhesive materials tested in the present study, the MMA monomer was present only in the visio.link structure. Consistent with the literature, the highest SBS values were observed in the visio.link application groups. In addition, the higher SBS values of the visio.link groups may be related to the pentaerythritol structure, which is one of the main components of the material. The high capacity of pentaerythritol to modify the PEEK surface may have led to statistical differences between visio.link and other adhesive materials that contained methacrylate monomers or different forms of methacrylate.⁶ It has been reported that pentaerythritol dissolves the PEEK surface, whereas MMA monomers form active reaction surfaces by swelling the dissolved surface and

Table 3 Percentage values by weight of the elements detected on specimen surfaces after adhesive application.

Element		Group (n = 3)					
		C	A	G	P	S	V
Mean weighted % (± SD)	C	52.27 ± 3.57	64.32 ± 0.52	60.39 ± 0.17	54.65 ± 1.13	53.58 ± 1.40	56.6 ± 2.49
	O	30.44 ± 2.85	32.29 ± 0.57	38.87 ± 0.16	37.51 ± 4.87	28.45 ± 1.31	36.98 ± 7.42
	Ti	7.59 ± 6.08	1.17 ± 0.19	0.73 ± 0.01	1.2 ± 0.13	0.88 ± 0.69	0.79 ± 0.07
	Si	4.59 ± 6.32	2.22 ± 0.92	NA	6.49 ± 3.66	17.08 ± 1.23	16.85 ± 0.02
	Al	6.63 ± 5.36	NA	NA	0.64	NA	NA
Element ratios	C/O	1.71	1.99	1.55	1.45	1.88	1.53

NA, not available; SD, standard deviation.

bonding to the composite resin veneers.²² It is thought that this mechanism brings about an increase in SBS.²² On the other hand, it has been reported that using adhesives that contain 10-Methacryloyloxydecyl dihydrogen phosphate (10-MDP) has a negative effect on SBS.²² This is because the functional group of the MDP monomer is occupied by a phosphate group that cannot chemically react with the PEEK substrate or the composite resins.²² The present study showed that the SBS of the adhesives that contained MDP particles was lower than visio.link groups regardless of the type of composite resin.

Hydroxyethyl methacrylate (HEMA) is also a mono-methacrylate known not to provide good long-term bond strength.²³ In the present study, only two adhesive systems (Adhese Universal and Single Bond Universal) containing the HEMA group were tested, and in accordance with the literature, the SBS values of these adhesive systems were lower than those of the P_D and G_{IN} groups, to which HEMA-free adhesive materials were applied.

The solvent in the adhesive material is also an important factor for crosslinking polymers. The solvent particles help the adhesive material to penetrate the polymer's structure.¹⁷ Adhese Universal and Single Bond Universal materials contain ethanol as a solvent. It can penetrate deeper into the PEEK surface, but this may cause some adverse effects on adhesion. These may occur because of the disappearance of the adhesive material in the PEEK material structure and the absence of a reaction between the composite resins.^{17,23} In the present study, the SBS values for the Adhese Universal and Single Bond Universal adhesive groups were lower than for other groups. This result may be related to the ethanol solvent in the adhesive material. These results were in contrast with those reported by Lümekemann et al²³, who tested similar universal adhesives (Adhese Universal, Scotchbond Universal [3M and G-premio BOND]). Adhese Universal and Scotchbond Universal had higher tensile bond strength (TBS) values than G-Premio BOND. It is possible that the different findings reported by Lümekemann et al²³ came from combining adhesive materials with resin cement and using the TBS test.

Some of the present results may be due to the presence of substances in the universal adhesive materials that are not reported by the manufacturer but that may promote adhesion to PEEK surfaces. The data provided by the manufacturers about the composition of their materials are very limited. This not only makes it difficult to compare the results from different studies, but also negatively affects the authors' ability to reach a definitive conclusion about the effects of materials on PEEK bond strength.^{15,22,23}

The EDS analysis showed that there were more elements on the surfaces of the samples in the control group than on those where adhesives were applied. The amounts of Ti and Al were much higher in the control group than in the other groups. It is thought that Ti particles are exposed through the airborne-particle abrasion process in PEEK materials, and after this process, Al particles remain on the surface due to the sand content. The SEM images of the groups where adhesive had been applied showed that the adhesive materials spread and filled the microporous areas on the materials' surface. This was different from the control group. A possible reason for this is that the diversity of elements and the ratios detected where adhesive material was applied were lower.

There is still no clear information about bonding composite resins to PEEK surfaces. The results of many studies on this subject are controversial and contradictory.^{7,12,15,16,25} In the present study, when each adhesive system was evaluated within itself, it was determined that indirect composite application exhibited higher SBS values in all adhesive groups except the G-Premio BOND groups (P_D and P_{IN}). For them, the P_D group exhibited higher SBS values than the P_{IN} group, but the difference was not statistically significant ($P > 0.05$). The higher SBS values obtained from application of Essentia direct composite combined with G-Premio BOND adhesive material may be due to the fact that this adhesive is recommended in the manufacturer's instructions for the composite material. On the other hand, using different composite resins after application of the same adhesive led to a statistical difference only in the G_D and

G_{IN} groups ($P < 0.009$). The change in the type of veneer did not make a statistically significant difference in any other adhesive group ($P > 0.05$). The difference in SBS values between the G_D and G_{IN} groups could not be fully explained. In general, adhesive materials have different compositions according to their intended use, and it should not be expected that systems developed mainly for the adhesion of resin materials will guarantee adequate adhesion to PEEK in every application.¹⁸

Some previous studies have shown that the mechanical adhesion of composite resin veneers to the adherent surface depends on the viscosity of the material and thus the weight percent of the filler content. An increase in the particle content increases the material's viscosity, and this might negatively influence mechanical retention. Also, the chemical composition and low surface energy of PEEK can cause difficulties in bonding with composite resins. To solve this problem, it is known that in addition to micromechanical bonding, chemical bonding provided by adhesive materials is required.²⁴ When the direct and indirect composite that was preferred in the current study was examined in terms of filler content and viscosity, Essentia direct composite and Gradia Plus indirect composite contained 81% and 80% filler by weight, respectively. The results also showed that their viscosity was also comparable (0.34 to 0.36 kPa s for Essentia and 0.41 to 0.43 kPa s for Gradia Plus).²⁶ In the present study, indirect and direct applications of composites did not have a significant effect on the SBS, except for in the two adhesive groups. This can be explained by the similarity of the filler content and the viscosities of the materials. In addition, some researchers have found that the viscosity of the composite resins does not affect the quality of adhesion.¹⁵

In some studies focusing on the SBS values of veneered PEEK materials, results were obtained that support the present findings.^{5,27,28} In a recent study comparing direct composite, indirect composite and flowable composites used in the veneering process, regardless of the PEEK material and surface treatments employed, it was determined that material viscosity was one of the most effective factors.²⁷ It was observed that flowable composites exhibited the highest SBS value in groups where the same main material and surface treatment were applied, and the current result was associated with the wettability of the surface. The viscosity parameter and filler ratios of the veneer material are critical in eliminating the disadvantage of the low surface energy of the PEEK material.^{5,28} In the present study, the selection of composite materials that were very close to each other in terms of these two par-

ameters may have been insufficient to reveal the possible effect of the veneering type on bond strength. It is critical to eliminate these scientific uncertainties by repeating this study with direct and indirect composites with different filler ratios and viscosities in the future.

Other studies have shown that SBS values higher than 10 MPa are clinically acceptable.^{15,19} In this context, SBS values of all adhesive materials and combinations of composite resins in the present study were above this limit. These results showed that it is possible to use alternative materials when visio.link cannot be used. On the other hand, using airborne-particle abrasion as the initial surface treatment caused even the control groups (C_D and C_{IN}) to exhibit SBS results above the 10 MPa threshold. This means that airborne-particle abrasion is extremely important for adhering to the PEEK surface, as other studies have found.^{14,24}

The present study has some limitations. To the best of the authors' knowledge, it is the first study to test direct and indirect veneering with composite resins and different combinations of universal adhesive materials and to compare the effectiveness of these materials on the SBS of PEEK materials. Thus, it was difficult to compare these findings with those of previous studies. In the present study, thermal cycling was used for artificial aging, and this may have affected the materials in two different ways. First, it might have increased the SBS caused by post-polymerisation in the contact area between the PEEK surface and the adhesive material and the composite resins. Second, the thermal stress from this aging method may have caused the materials to exhibit different volumetric changes and created mechanical stress in the adhesion area.^{18,21,29} Therefore, to better understand the effect of the aging method, it is important to examine groups that are not subjected to the aging procedure. In addition, only 5000 cycles were used in the aging protocol in this study, but it is clinically important to investigate how the SBS values are affected after long-term aging procedures. Intraoral conditions could not be imitated fully in the present study; however, the results may provide clinicians with insight into alternative adhesive materials that can be used to achieve reliable bond strength between PEEK materials and different composite resins. Thus, more *in vivo* and *in vitro* studies are needed to evaluate the long-term clinical performance of both adhesive systems and composite resin veneers.

Conclusion

The visio.link groups (V_{IN} and V_D) showed the highest SBS results, followed by the P_D and G_{IN} groups. The type

of composite resin veneer did not make a significant difference in terms of SBS values for both visio.link and the tested universal adhesives, except for Gluma Bond Universal. All the tested universal adhesives showed clinically acceptable SBS results.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Dr Cinel Sahin contributed to the conception, methodology, experiment and manuscript draft; Dr Mutlu-Sagesen contributed to the data analysis; Drs Karaokutan and Özcan contributed to the editing and revision of the manuscript. All the authors approved the final version of the manuscript.

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