Original Article

Evaluation of the failure modes and load-bearing capacity of different surface-treated polyether ether ketone copings veneered with lithium di-silicate compared to polyether ether ketone copings veneered with composite: An *in vitro* study

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Abstract

Aims: The purpose of this study is to compare and evaluate the failure modes and load-bearing capacity of different surface-treated polyether ether ketone (PEEK) copings when veneered with lithium di-silicate with that of PEEK veneered with composite.

Settings and Design: *In vitro*; comparative study.

Materials and Methods: Congruently anatomically shaped single unit PEEK copings ($n = 40$) were fabricated by scanning a prepared typodont tooth. The PEEK copings were subdivided among four groups ($n = 10$/group). Among all, one group of PEEK coping was veneered with Urethane dimethacrylate (UDMA)-based composite and other groups were veneered with lithium-di-silicate after different surface treatment on peek copings, i.e., (i) composite veneered PEEK fixed dental prosthesis (FDP) (control group: Group PC), (ii) lithium di-silicate veneered PEEK FDP (no surface treatment: Group PCeN), (iii) lithium di-silicate veneered PEEK FDP (sandblasting with 50 μm alumina: Group PCeS), and (iv) lithium di-silicate veneered PEEK FDP (chemical etching with 98% sulfuric acid: Group PCeE). The load-bearing capacity of all specimens was assessed using a universal test machine. All the samples were loaded till the cracking point and load at that point and failure modes were noted down.

Statistical Analysis Used: One-way ANOVA and post hoc Tukey tests.

Results: The highest load-bearing capacity was recorded for lithium di-silicate veneered PEEK copings which were chemically etched with 98% sulfuric acid (Group PCeE: 1040.25 ± 77.46) followed by Group PCeS (1017.20 ± 53.70), then Group PC (965 ± 51.57) and least was for Group PCeN (933 ± 97.54). There was a significant reduction in mean load-bearing capacity in Group PCeN ($P < 0.05$).

Conclusions: Veneering of PEEK with pressed lithium di-silicate seems to be a viable clinical option in terms of adequate load-bearing capacity. Lithium di-silicate veneered PEEK FDPs were successful against physiological occlusal forces and are a suitable material for FDPs.

Keywords: Ceramic veneered polyether ether ketone, load-bearing capacity, polyether ether ketone

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INTRODUCTION

In prosthetic dentistry, there is an increase in demand of esthetics, biocompatibility, and materials with low plaque affinity which promote periodontal health.[1] Metal ceramic fixed dental prostheses (FDPs) are considered as gold standard,[2] but their metallic hue is unavoidable and chances of hypersensitivity reaction have always been an issue.[3] All ceramic prostheses are used in esthetic dentistry due to their high esthetics, excellent mechanical properties, and biocompatibility but were rejected due to their low impact strength.[4] Zirconia-based restorations are most commonly used esthetic restorations. They have high mechanical strength but lack tensile strength and adequate etching properties. Monolithic zirconia has vastly broadened the range of its applications in dentistry, but it still has some limitations. Its radio-opaque nature preludes the detection of caries without prior removal of prosthesis. There is a problem of porcelain cracking as well.[5] Zirconia porcelain interface is susceptible to crazing and chipping during function.[6] To evade such problematic situations, a newly engineered polymer is suggested for dentistry: Highly resistant polymers are known as polyether ether ketone (PEEK).[7]

PEEK is high-performance semi-crystalline thermoplastic material which has a high melting point of 335℃, good dimensional stability, stiffness, and chemical stability against all organic and inorganic chemicals.[8] PEEK's radiolucency, rigidness, low plaque affinity, and inertness make it the perfect choice for dental restorations. PEEK was introduced into the field of dentistry for its use as transitional abutment, healing abutment, and dental clasps. It has also been utilized as a rigid material for RPD frameworks and FDPs.[9] However, the grayish hue and high opacity are the main disadvantages of PEEK which limits its usage in the esthetic zone. Therefore, PEEK is layered with UDMA light cure composite or PMMA facing to stimulate the "natural tooth appearance."

Composite layered PEEK has several limitations. It gets discolored over a period of time. Ozarslas MM stated that the discoloration of dental prosthesis after a certain period of time has always been a problem. Composite layered PEEK gets discolored over a period of time. This discoloration is determined by either extrinsic factors such as beverages containing caffeine, mouth rinses, smoking, or intrinsic factors such as the chemical reactions of restorative materials triggered by processing mode of placed restoration.[10] The wear resistance of composite layered PEEK is low, which makes them unable to bear masticatory forces, and gets worn off in due course of time.

Systematic reviews reveal that posterior teeth restorations with resin composite undergo destructive forces and chemical injuries, such as masticating hard food and inattentive attrition and bruxism leading to their wear,[11] whereas ceramics are resistant to wear and have greater color stability.[12] Due to the above-mentioned advantage, it would be wonderful if lithium di-silicate can be veneered on PEEK to get the combined advantage of both high wear resistance and color stability of ceramic along with better mechanical and chemical properties of PEEK.

PEEK has a lower surface free energy and inert hydrophobic surface resulting in poor adhesion with composite.[9] Investigations on surface pretreatments of PEEK show that sulfuric acid-etched surface luted with self-etch resin cements displayed better shear bond strength than air abrasion (50–110 μm), hydrofluoric acid, argon plasma, and silica coating.[13] It has been recommended to use 98% H_2SO_4 to alter the mechanical and surface characteristics of PEEK for improving the luting surface. 98% sulfuric acid creates sulphonate groups in PEEK's polymeric chains which gets cross-linked to MMA dental adhesive.[14] Hence, surface pre-treatment of PEEK prior to adhesive application improves its micromechanical bonding surface, especially using 98% sulfuric acid and sandblasting with 50–100 μm alumina.

With the advancement of new computer-aided design (CAD)/computer-aided manufacturing systems and new surface treatment protocol, veneering with lithium-di-silicate on PEEK seems a viable treatment option. After extensive literature research, the available information on luting PEEK copings with lithium-di-silicate after different surface pretreatments is very limited. The null hypothesis formulated as no significant discernible variation in load-bearing capacity among all PEEK copings veneered with composite and different surface-treated PEEK copings veneered with lithium di-silicate using appropriate luting agent. An *in vitro* study was planned to assess load-bearing capacity and compare failure modes of different surface-treated PEEK copings veneered with lithium di-silicate with that of PEEK copings veneered with composite.

MATERIALS AND METHODS

Tooth preparation
The study was approved by the institutional review board (No F/18/81/MAIDS/Ethical Committee/2016/3166-67). For this *in vitro* study, the sample size was taken as *n* = 40. The sample size was calculated after a comparison of two means using a power of 90%. In this study, a mandibular

typodont model was used (FrasacoA-3, Germany) and the left first mandibular molar was prepared for full-coverage crown using an airotor handpiece with diamond points. The tooth preparation involved 2 mm of occlusal reduction, overall axial preparation of 1.5 mm, and a 360° heavy chamfer of 1 mm with a taper of 6°. Axial reduction was done employing depth grooves, thereby rendering uniform reduction. Standard grit round end diamond point (blue band) was used to complete the preparation maintaining the desired depth. Preparation was finished using fine-grit round end diamond point (yellow band).

### Fabrication of the polyether ether ketone framework test samples

The PEEK FDPs were fabricated using rapid prototyping techniques (subtractive). This was followed by veneering with UDMA-based composite in case of 10 PEEK copings and lithium disilicate veneering on differently surface-treated 30 PEEK copings. To avoid confounding variables, the same milling machine was used for fabrication of all 40 PEEK FDP copings. The study design is shown in Figure 1.

40 polyether ether ketone fixed dental prosthesis copings ($n = 40$)

The prepared typodont model was scanned using the Identica Hybrid Scanner, MEDIT. The scanning was done using 3-axis impression scanning technique to prepare the computerized die. The scanned data were thereafter sent to the DentalCam 7 software (VHF, Germany) [Figure 2]. This CAD data were used to design the required PEEK coping of 0.5 mm thickness. On the basis of the master design, the milling process was undertaken. The 4-axis milling process was carried out using the K4 milling machine (VHF, Germany). 40 standardized PEEK copings were milled using dry machining/milling. The PEEK dental disks (BIO-HPP, Bredent, Germany) with A2 shade were used.

Composite veneered polyether ether ketone ($n = 10$)

The PEEK copings underwent airborne abrasion with 50 µm particle for 45 s at 10 mm distance (Macro Dental, India) and were cleaned in an ultrasonic bath for 5 s as a normal procedure for composite veneering. The PEEK copings were conditioned using visio.link (Bredent, Germany). This conditioning agent consisted of methylmethacrylate, pentaerythritol triacrylate, and photoinitiators and underwent light activation at 220W/cm² for 90 s (bre.Lux; Bredent). UDMA-based composite (Visio.lign, Bredent) was used for veneering. A full-contour wax-up was done on the master model. Using this wax-up of the master
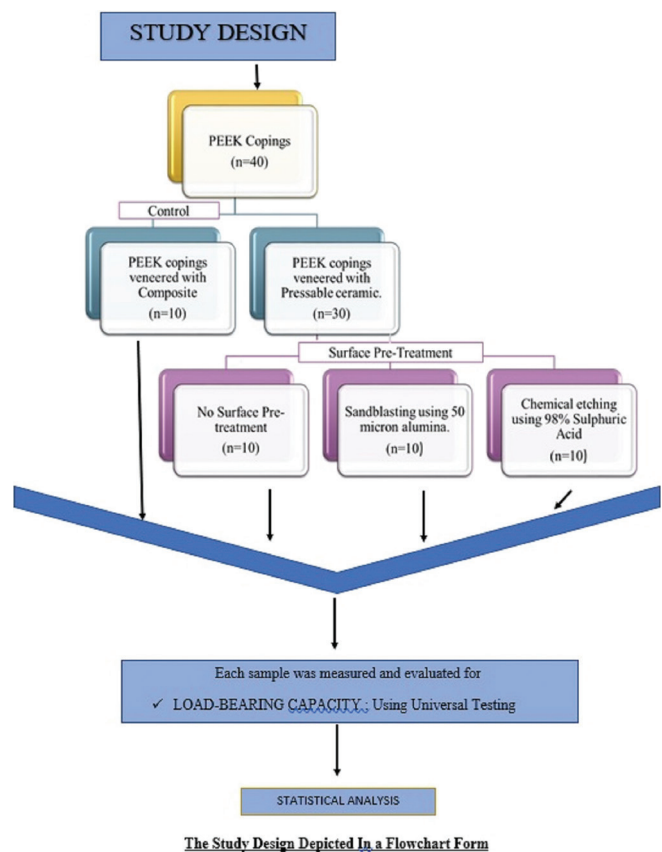
Figure 1: Study design, division of specimens according to different surface pretreatments, veneering composite resin, and lithium disilcate veneering

model, a silicone index (Zetaplus, Zhermack, Italy) was created, enabling for a consistent and repeatable anatomic form fabrication. After utilizing the incremental method to apply the veneering composite resin on the PEEK coping, excess material was eliminated when the silicone mold was overlaid. The occlusal height of the composite was around 1–1.5 mm. Layering was followed by light polymerization for 180 s with bre.Lux power unit 2 (Bredent, Germany). The power unit makes use of full-range LED light with an in-built temperature control system. All the 10 samples of composite veneered PEEK were finished and polished and were stored in a dry environment [Figure 3].

Surface treatment of polyether ether ketone copings
- Sandblasting with 50 µm alumina ($n = 10$)
  - The PEEK copings were airborne abraded with 50 µm alumina for 45 s at a 10 mm distance. (Macro Dental, India)
- Surface treatment with 98% sulfuric acid ($n = 10$)
  - The PEEK coping's external surface was etched with 98% sulfuric acid (Replicon Scientific, Gurgaon, Haryana) for 60 s. The acid was neutralized using deionized water
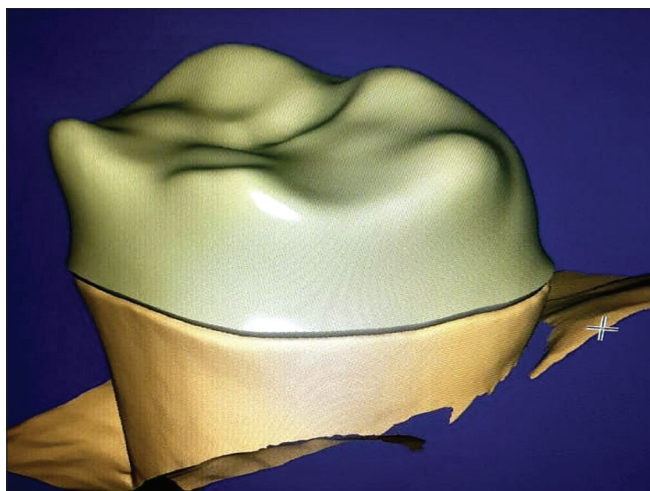
Figure 2: Computer-aided design designing of polyether ether ketone coping

Figure 3: Composite veneered polyether ether ketone fixed dental prosthesis

(Hriveram, Ahmedabad, Gujarat) for 60 s and oil-free compressed air was used to dry it.

Fabrication of lithium di-silicate shells

To fabricate E-max shells, the wax pattern for shell was fabricated using a K4 Milling unit. On the basis of the master design, the milling process was undertaken. The 4-axis milling process was carried out using the K4 milling machine (VHF, Germany) 30 standardized wax patterns of thickness 1 mm were cut from the hard-wax disks used in milling. The wax shell was invested in a refractory medium. The lithium di-silicate shell was fabricated using conventional "Lost wax technique." After investment, the burnout procedure was carried out at 850°C and holding time was kept 1 h. Entry temperature of pressing furnace was done at 700°C in the furnace unit (Programat EP 3010, Ivoclar Vivadent, Germany). Lithium di-silicate ingots (IPS e.max MT, Ivoclar Inc) were pressed at 5 bars pressure. The lithium di-silicate shells were finished and polished after pressing. For polishing, final glaze firing was carried out on all 30 lithium di-silicate shells in a ceramic layering furnace (Ceramco furnace unit, USA).

Lithium di-silicate veneered polyether ether ketone (*n* = 30)

The PEEK coping was conditioned using visio. link (Bredent, Germany). This conditioning agent consisted of methylmethacrylate and pentaerythritol triacrylate. The E-max shell of 1 mm thickness was conditioned using K Primer of DTK adhesive (Bredent, Germany) and was left over for 10 s.[15] K primer is resin-based primer containing 10-methacryloyloxydecyldihydrogen phosphate. The DTK adhesive (Bredent, Germany) was applied on the bonding surface of lithium di-silicate shell and was luted to PEEK coping. Lithium di-silicate shell which was luted to the PEEK coping was kept in alignment apparatus under

25 kg force to standardize the seating pressure during luting procedure.[16] The assembly was left over for 1 h for final polymerization of resin cement. All the 30 lithium di-silicate veneered PEEK copings were finished and polished and were stored in a dry environment.

Fabrication and setup of a metal die

Direct metal laser sintering was used to create cobalt-chrome (Starbond CoS, Scheftner, Germany) metal dies for the prepared teeth. The Identica Hybrid Scanner was used to scan the prepped tooth, and the resultant CAD software was used to fabricate the stereolithographic file for metal die. By coating 0.8–1 mm of the root section of the die with polyether polymer (Impregum; 3M ESPE), the periodontal ligament's resiliency was mimicked. The polyether-coated roots were embedded in a self-polymerizing resin base (DPI-RR, India) that was inserted up to 2 mm below the preparation margin.

Determination of load-bearing capacity

Each PEEK veneered FDP was placed over the metal die and was loaded till a crack occurs. This was done using a Universal Testing Machine (model No: UNITEST-10, ACME) [Figure 4] which was attached to a connecting laptop, which had an in-built software (ACME, INDIA). The crosshead speed was 1 mm/min. A metal plunger with a diameter of 5 mm was then used to load the force into the central fossa of the occlusal surface of the crown. The amount of force was steadily increased from zero to a point where it abruptly decreased by more than 20 N. This sharp drop suggested that the sample had fractured. The force of fracture was calculated from the highest force up to the point of rapid decline. The location of cracks and fragmentation of core and/or veneering materials were also analyzed during the visual examination. The failures are of three types: cohesive

failures, adhesive failures, and mixed failures. Crack location would be assessed, whether the crack is present in PEEK coping, composite, or in lithium di-silicate shell. Fragmentation of veneering material would be assessed for crack and for bulk fracture.

Statistical analysis

The data were collected in Newton (N) for load-bearing capacity. Descriptive statistics (mean, standard deviation,) were computed for each group [Graph 1]. A one-way ANOVA analysis was used to test for significant differences between the groups, followed by a Bonferroni *post hoc* test (preset = 0.05). Statistical Package for the Social Sciences was used to do a *post hoc* power analysis (SPSS Inc. Chicago, IL, USA version 26). The level of significance was set at 5% ($P < 0.05$).
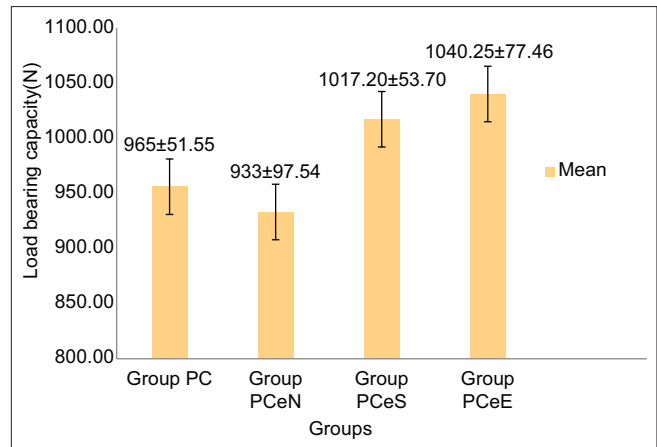
RESULTS

Surface morphology after etching

External surface of PEEK coping underwent pretreatments using 50 μ alumina and 98% sulfuric acid before luting it with lithium di-silicate Shell. The untreated PEEK surface [Figure 5] was kept as a control surface to analyze the characteristics after pretreatments. Distinct surface modifications were visible under an electron microscope with both the pretreatments. On PEEK's external surface, sandblasting with a particle size of 50 μ alumina resulted in an irregular surface that was more jagged in comparison to untreated PEEK coping. Chemical etching with 98% sulfuric acid resulted in a complex fiber network with a porous surface. At higher magnification, the H_2SO_4 resulted in a blister and porous surface [Figure 6]. This zone is accepted to form apparent tag formation with resin material.

Load-bearing capacity measurement

Table 1 shows the load-bearing mean, maximum and minimum values, and standard deviations for each group. The load-bearing capacity (in newtons, N) data were compared statistically using one-way ANOVA [Table 2] and the intergroup comparison of mean Load-bearing capacity was done in accordance to Tukey-HSD tests [Table 3]. The highest load-bearing capacity was recorded for lithium di-silicate veneered PEEK copings which were chemically etched with 98% sulfuric acid (Group PCeE: 1040.25 ± 77.46) followed by Group PCeS (1017.20 ± 53.70), then Group PC (965 ± 51.57) and least was for Group PCeN (933 ± 97.54). A significant reduction in load-bearing capacity was seen in Group PCeN ($P < 0.05$). The mean fracture load was significantly more among Group PCeE in comparison to Group PCeN ($P < 0.05$). No significant differences were seen in mean fracture load among groups PCeN and PCeS.

Graph 1: Bar-chart presentation of the results of the load-bearing tests (mean values and standard deviations) of different groups

Figure 4: Universal testing machine used to measure load-bearing capacity for polyether ether ketone fixed dental prosthesis
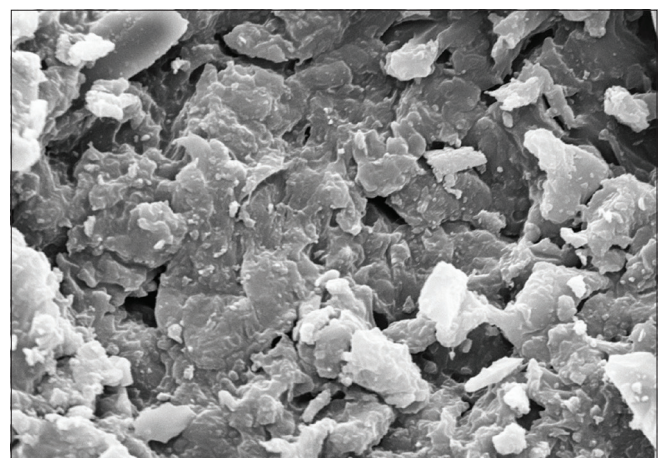

Figure 5: Surface topography: Untreated polyether ether ketone surface (×5000)

Analysis of failure mode

After loading to fracture, visual and light microscopic (Motic BA210, China) analysis was carried out for all the

40 PEEK FDPs to establish the fracture modes. Visual analysis of all fractured samples was done for evaluation of crack location and fragmentation with respect to veneering and core materials. To eliminate bias, the fracture mode was analyzed by other examiners, any disagreements were solved by discussion or third author suggestion if needed.

Three separate failure types were used to determine the fracture mode of the PEEK FDPs: cohesive (chipping of veneered material), radial cohesive fracture, and adhesive failure (debonding of veneering material from substrate). The following is a list of the fracture modes:
- All the samples in PEEK FDPs in Group PC suffered adhesive failures pertaining to marginal ridge area [Figure 7]
- Composite chipping was seen in three composite veneered PEEK FDP's out of ten, with detachment of veneering material
- In lithium di-silicate veneered PEEK FDPs, all the samples suffered adhesive failures with detachment

of lithium di-silicate shell from core. Seven ceramic veneered FDP had ceramic chips off with complete debonding of lithium di-silicate shell
- In all lithium di-silicate veneered PEEK FDPs, all the PEEK cores were intact and none of them underwent any type of failure
- 10 out of 40 PEEK FDPs showed chip-off fractures.

DISCUSSION

The composite veneered PEEK has been in clinical use for a quite some time now, but there is a lack of literature on Lithium di-silicate veneered PEEK. The study's goal was to see how well composite veneered PEEK copings could withstand loads with that of lithium di-silicate veneered PEEK copings with or without surface modifications through an *in vitro* setup. The load-bearing fracture was evaluated for four groups: Group PC, Group PCeN, Group PCeS, and Group PCeE. Out of them, the highest load-bearing capacity was recorded for lithium di-silicate
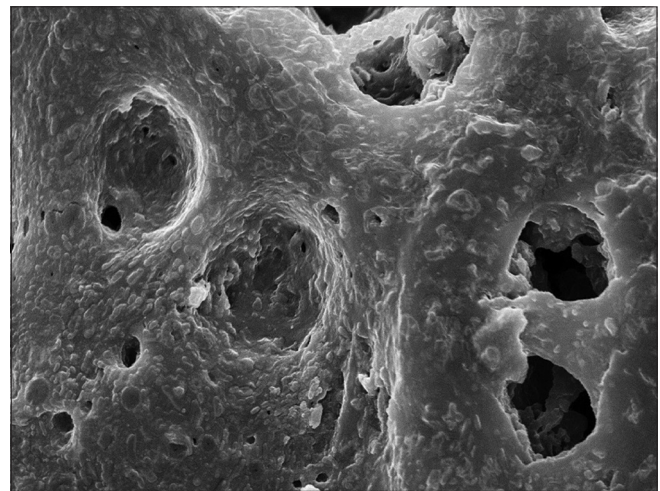
Table 1: Descriptive statistics for load-bearing capacity (*n*) for each group tested

Groups	Minimum	Maximum	Mean	SE	SD
Group PC	856.50	1024.50	956.05	16.30	51.56
Group PCeN	786.60	1042.50	928.71	28.96	91.57
Group PCeS	942.50	1108.50	1017.20	16.98	53.71
Group PCeE	905.50	1188.00	1040.25	24.50	77.47

PEEK: Polyether ether ketone, PC: Composite veneered PEEK FDP, PCeN: Ceramic veneered PEEK without any pretreatment, PCeS: Ceramic veneered PEEK (sandblasting with 50μ Alumina), PCeE: Ceramic veneered PEEK (chemical etch with 98% sulfuric acid), SD: Standard deviation, SE: Standard error, FDP: Fixed dental prosthesis

Table 2: One-way ANOVA results for comparison of load-bearing capacity for intergroup analysis

Analysis	Sum of squares	df	Mean square	*F*	Significance
Between groups	76091.54	3	25363.85	4.82	0.006
Within groups	189525.54	36	5264.60		
Total	265617.08	39			

Figure 6: Surface topography: Etched with 98% sulfuric acid (×5000)

Table 3: *Post hoc* Tukey test for intergroup comparision

Group	Comparison group	Mean difference	SE	Significance	95% CI (lower limit-upper limit)
Group PC	Group PCeN	22.94	32.45	0.894	−64.45-110.33
	Group PCeS	−61.15	32.45	0.253	−148.54-26.24
	Group PCeE	−84.20	32.45	0.062	−171.59-3.19
Group PCeN	Group PC	−22.94	32.45	0.894	−1s 10.33-64.45
	Group PCeS	−84.09	32.45	0.063	−171.48-3.30
	Group PCeE	−107.14	32.45	0.011	−194.53-19.75
Group PCeS	Group PC	61.15	32.45	0.253	−26.24-148.54
	Group PCeN	84.09	32.45	0.063	−3.30-171.48
	Group PCeE	−23.05	32.45	0.892	−110.44-64.34
Group PCeE	Group PC	84.20	32.45	0.062	−3.19-171.59
	Group PCeN	107.14	32.45	0.011	19.75-194.53
	Group PCeS	23.05	32.45	0.892	−64.34-110.44

PEEK: Polyether ether ketone, PC: Composite veneered PEEK FDP, PCeN: Ceramic veneered PEEK without any pretreatment, PCeS: Ceramic veneered PEEK (sandblasting with 50 μ alumina), PCeE: Ceramic veneered PEEK (chemical etch with 98% sulfuric acid), FDP: Fixed dental prosthesis, SE: Standard error, CI: Confidence interval

Figure 7: After fracture load measurements. Adhesive failures between polyether ether ketone framework and veneering lithium di-silicate

veneered PEEK copings which were chemically etched with 98% sulfuric acid (Group PCeE: 1040.25 ± 77.46) followed by Group PCeS (1017.20 ± 53.70), then Group PC (965 ± 51.57) and least was for Group PCeN (933 ± 97.54). In all four groups, the mean forces were 1.21%–263% higher than 400 N, which is the minimum required for any material to withstand occlusal forces in the posterior region.[17] The mean maximum bite force during mastication has been reported to range between 216 and 847 N in various studies; the highest bite force is seen in the first molar region: 807 N for men and 650 N for women. When biting force is applied to an object, these values can rise to 965 N. As a result, it is fair to assume that an initial fracture resistance of 900 N is required for a posterior prosthesis to have a good clinical prognosis. The load-bearing values of all 40 specimens in the current investigation surpassed 933 N, indicating that the load-bearing findings in all groups demonstrated adequate fracture strength against physiological occlusal pressures. The fracture load of 3-unit PEEK frameworks was about 1383 N in a study by Stawarczyk *et al*.[18] The mean fracture load in this research, however, was about 988 N. When compared to veneered PEEK FDPs, unveneered PEEK FDPs may have a higher fracture load. However, veneered FDPs must be assessed because the latter maintains the clinical benchmark due to their esthetics. However, the striking contrast in load-bearing capacity that is evident between nonveneered and veneered FDPs suggests that either that there are some inner tensile forces that are generated post veneering or the cohesive force between the veneering composite and PEEK is not that strong. As 98% sulfuric acid provides maximum surface roughness and increased surface area, a similar rise in mean fracture load is found in Group PCeE, followed by Group PCeS.

The least fracture strength was with Group PCeN, as in this case, the PEEK surface was not etched at all. Therefore, there was an adhesive failure between lithium di-silicate and PEEK coping at a relatively lower value. An intergroup comparison was done using one-way ANOVA and the variance was verified using *post hoc* Tukey tests. A statistically significant difference was seen in mean load-bearing capacity between Group PCeE and Group PCeN, which is in accordance to previous literatures.[9,19,20]

In case of composite veneered PEEK FDP, all the 10 samples suffered adhesive failures pertaining to the marginal ridge area. Composite chipping was seen in some cases with detachment of veneering material. All the PEEK cores were intact and none of them underwent any type of failure. According to Bulent Kadir Tartuk,[21] the composite veneered PEEK suffered adhesive failures which are in accordance to our study. The reason is attributed to poor bonding surface between PEEK and veneering material. The chipping was observed in composite layered PEEK FDPs at the marginal ridge area. The fracture/chipping occurred even after strict clinical and laboratory protocol. Even after following all clinical and laboratory protocols, the fracture/chipping happened. Inadequate curing, composite stacking, reduced material thickness, and bonding surfaces between composite and PEEK core framework are all possible causes.[22] The cause for this may be linked to material bonding and thickness in this investigation. Chipping can be caused by a variety of causes, including cuspal deflection caused by polymerization shrinkage stress. It can be reduced by utilizing a gradual filling process and low shrinking composite. As measured by cuspal deflection, flowable composite lining under traditional composite layering does not reduce polymerization shrinkage stress and therefore can reduce composite adhesive failures.[23]

On visual analysis, the fracture was evident at lower values with that of Group PCeS and Group PCeE ($P < 0.05$). The low fractural strength of composite and lack of bonding surface between PEEK and composite can be attributed to the adhesive failures.

In case of lithium di-silicate veneered FDPs, an interesting fact has been observed that after the fracture of veneering material, the remaining lithium di-silicate gets deboned from the PEEK substructure. This finding was mostly seen in Group PCeN. In this group, no etching or surface treatment of PEEK coping was done, resulting in low bonding between PEEK and lithium di-silicate shell. Therefore, they too had devastating adhesive failures. The location of fracture in lithium di-silicate veneered PEEK is mostly along the central fossa of mandibular first molar.

The highest loads are concentrated in the central fossa resulting in shear stresses along the lateral surface of PEEK substructure. These shear stresses cause debonding of lithium di-silicate and fracture of veneering material.

Fracture features such as arrest line, compression curls, hackle, and twist hackle have been reported in the literature.[24] In the present study, fracture lines and cracks have been reported in lithium di-silicate veneered PEEK FDPs. Overall, the mean load-bearing force was highest in PEEK copings which were chemically etched with 98% sulfuric acid and least in PEEK coping with no etching protocol.

In the present study, the null hypothesis was not rejected as there is no statistical difference in load-bearing capacity between composite veneered PEEK FDP and lithium di-silicate veneered PEEK FDP ($P > 0.05$) However, there is a statistically significant difference between load-bearing capacity of lithium di-silicate veneered PEEK with no etched lithium di-silicate veneered PEEK with chemical etching with 98% sulfuric acid ($P < 0.05$). Both the composite veneered PEEK and lithium di-silicate veneered PEEK meet the required fractural strength of 400 N,[25] which is the minimal requirement for a prosthetic FDP material to be used in the posterior region to withstand occlusal forces. In the present study, none of the PEEK cores were fractured. The present study was an *in vitro* study. As a result, clinical studies are needed to provide clear proof of long-term dependability in *in-vivo* settings. In the present *in vitro* study, the effect of saliva, mastication, and the aging procedure was not taken into consideration. Hence, in further studies, long-term thermocycling with a mechanical chewing simulator should be considered. Moreover, while conducting the fracture analysis of PEEK samples, it is evident that bonding interface plays a pivotal role in the determination of the load-bearing capacity of the FDP.

It is clear that substantial surface cleaning and roughening (Al2O3, tribochemical treatment, H2SO4) is required to create a strong connection between PEEK and the veneering composite. For adhesive bonding, it may be necessary to treat the surface before applying the cement. Surface roughening, followed by phosphate-based or acetone-based methacrylate, or tribochemical treatment, enables PEEK surfaces to achieve maximal binding strength and is an area of further research.[26]

Based on the result and observations made during the study, certain limitations were encountered. Keeping in mind the limitations, certain recommendations need to be suggested as follows:

1. This was an *in vitro* research project. As a result, clinical studies are necessary to generate proof of long-term dependability in *in-vivo* settings
2. In the present study, the effect of saliva, mastication, and the aging procedure was not followed. Hence, in further studies, long-term thermocycling with a mechanical chewing simulator should be considered
3. While calculating the load-bearing capacity, the force was concentrated only at the central fossa region resulting in early fracture. Hence, in future experiments, the force should be distributed all along the occlusal surface
4. The main fracture type encountered in PEEK FDPs was the adhesive type. Hence, there is a need to carry out further research on the surface treatments of PEEK FDPs to further improve the bond between PEEK and its veneering material
5. It is considered as a pilot study and planning of an elaborate study with a larger sample size and inclusion of more parameters is suggested.

CONCLUSIONS

The following key findings may be derived within the constraints of this laboratory study:
1. Mostly the failure advocated in composite veneered PEEK FDPs and lithium di-silicate veneered PEEK FDPs were of adhesive type
2. Lithium di-silicate veneered PEEK can be advocated as a fixed dental prosthetic material as it can bear normal masticatory load of 400 N.
3. There is a need to carry out further research on the surface treatments of PEEK FDPs to further enhance the bond between PEEK and its veneering material
4. It is important to investigate the strength of FDPs under clinical circumstances
5. Micro mechanical locking from bonding agent penetration in the pits and grooves appears to be the most important element in increasing adhesion between PEEK and the adhesive substance. As a result, it has been discovered that surface topography has an impact on load-bearing capacity.

Conflicts of interest
There are no conflicts of interest.

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