Retention Strength between Polyetheretherketone Abutments and Polymethyl Methacrylate Crowns Bonded with Different Types of Dental Cements

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Abstract

The objective of this study was to compare retention strength of various cement types in bonding polyetheretherketone (PEEK) abutments to polymethyl methacrylate (PMMA) crowns and their failure modes.

After PEEK abutments preparation, the surface roughness, surface topography and energy dispersive x-ray spectroscopy (EDS) analysis were examined to confirm the same surface characteristics. Then, fifty PEEK abutments were divided into 5 groups (n=10), one for each cement type. Clear PMMA crowns were cemented to abutments using zinc phosphate cement (ZPC), zinc oxide temporary cement without eugenol (Temp-Bond™ NE) and three resin cements (RelyX™ U200, Panavia™ F 2.0, and Superbond C&B®). The retention strength and failure modes were examined using a universal testing machine and stereomicroscope. The results were analyzed with One-way ANOVA at a significance level of 0.05.

The surface roughness, topography, and EDS analysis confirmed the same surface characteristic of all PEEK abutment specimens. Statistical analysis revealed significant difference across cements groups ($p<0.01$). The highest retention strength was Superbond C&B® followed by RelyX™ U200, Panavia™ F 2.0, Temp-Bond™ NE, and ZPC respectively. All of the specimens in each group exhibited mixed failure mode except the Superbond C&B® group.

Within the limitation of this in vitro study, Superbond C&B® exhibited the highest retention strength, whereas RelyX™ U200 , Panavia™ F 2.0, Zinc phosphate cement, and Temp-Bond™ NE failed to provide sufficient retention strength.

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Introduction

Implant-supported fixed partial denture is a favorable treatment option compared to conventional tooth-supported bridge due to their high success rates.[1-3] Therefore meticulous treatment planning such as placement position and abutment selection is essential in creating a proper emergence profile, adequate retention for the prosthesis, and good biologic response.[4] Normally, the two-piece implant abutment can be screw-, cement- or screw-cement retained on a prefabricated or customized abutment.[4] Several studies have discussed both the advantages and disadvantages.[5-7]

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Because of a paradigm shift of using non-metal materials, PEEK implants and abutments were introduced.[8] They can be fabricated by computer aided design and computer aided manufacturing (CAD/CAM) digital workflow and used as implant-supported provisional restorations, which is recommended for 1-3 months.[9] The advantages of PEEK over metal abutments are: 1) they can be adjusted easily at chairside, 2) improve esthetic results due to their white-opaque color which is less likely to cause greyish effect at gingival margin , 3) have less MRI distortion, 4) reduce the risk of metal allergic reaction and 5) have less or equal biofilm on surface.[10] Moreover, using PEEK healing abutments reduces the risks of bone resorption and soft tissue recession in initial healing phase.[11]

PEEK, a thermoplastic material, is inert to chemical reactions which causes problem in luting with other materials.[12-15] This may affect the retention of prosthesis on PEEK abutment. Retention of implant-support fixed restoration is one of an important factors of a prosthesis survival.[16] The retention and resistance of the prosthesis are associated with the geometry of the abutment, abutment height, surface area, surface roughness, type of cement used and cement space.[17-19]

Cement space usually depends on the type of cement used. The space should be sufficient to allow sealing and seating of the prosthesis, and is recommended at about 50 microns; 30 microns for cement film thickness and 20 microns for wax pattern distortion.[20] Nowadays, the latter distortion issue is reduced by using CAD/CAM system. It has been reported by a study that the ideal cement space varies from 20 to 40 microns.[21] Furthermore, using the CAD/CAM system can provide uniform cement space, which allows passive fit for cementation.[22]

Cement selection should be based on their properties, providing sufficient retention for normal mastication.[21] There are conventional cement and resin cements. A resin cement, either MMA- (eg. Superbond C&B®) or DMA-based (eg. RelyX™ U200, Panavia™ F 2.0) polymer, contain different types of functional monomer for chemical reaction.[23,24]

The Superbond C&B® contains 4-methacry-loyloxyethyl trimellitate anhydride or 4-META as a functional monomer while the RelyX™ U200 contains methacrylated phosphoric ester as a functional monomer. The Panavia™ F 2.0 contains 10-Methacryloyloxydecyl dihydrogen phosphate or 10-MDP as a functional monomer. In cases of provisionalization, a weaker cement, such as zinc phosphate cement (ZPC) and Temp-Bond™ NE, might be selected for ease of prosthesis removal. Retrievability should be permitted without any damage to soft tissue interface when removal for soft tissue molding, screw tightening, screw replacement, minor prosthesis adjustment, and periodic recall are needed.[25-27] Cement selection for luting crown to PEEK abutment is still inconclusive because of various protocols in several studies.[26-29]

Information about the PEEK abutment bonded to PMMA crown as a provisional restoration is scarce. Several studies have reported some complications such as cement breakage and fracture of provisional restoration [30-32].

The objectives of this study were to evaluate retention strength of PEEK abutments with various types of cement and their failure modes. The null hypotheses stated that there was no statistically significant difference of tensile bond strength between PEEK abutments and types of cement used ($p<0.05$).

Materials and methods

All the materials, substances and devices used in this study are presented in table 1.

PEEK abutment fabrication

PEEK abutment was designed in AutoCAD 2015 (Autodesk Inc., California, United States) as figure 1(A) and milled 56 abutments from the manufacturer.

Surface roughness test

Three abutments were randomly investigated with a profilometer (Surftest SJ-410 series, Mitutoyo, Kanagawa, Japan). A stylus gauge, traveling at a speed of 0.1 mm/s with a measuring track of 2 mm. and a cut-off set at 0.25 mm. was used. The tests were performed three times, the distance between parallel tracks was 0.5 mm. The mean roughness average (Ra) of each specimen was recorded.

Surface topography and EDS analysis

Topographical analyses were performed using a scanning electron microscope (SEM) (JSM-5910LV, JEOL, Peabody, MA, USA). Three randomly selected specimens (n=3) from each group were gold-sputtered and examined under the SEM at 2000x, 5000x and 20000x. The SEM was operated at 15.0 kV with a working distance of 10.0 mm. Data analysis software was used to analyze 3D topographical data. The primary chemical composition of PEEK was also obtained using an energy-dispersive spectroscopy (EDS) analysis.

Fabrication of clear PMMA crown

The design was carried out with SolidWorks version 2018 (Dassault Systèmes,Waltham, MA, USA) as demonstrated in figure 1(B). The internal surface of the crown was reversed from PEEK abutment stereolithography file(.stl). The cement space was set at 50 micron. Clear PMMA was selected as a material to fabricate 50 crowns by milling machine. They were also cleaned with deionized water for 5 minutes in an ultrasonic machine and stored in a dry place.

Materials	Manufacturers	Composition	Lot. number
Implant analogue	PW Plus, Nakhon Pathom, Thailand	Titanium	PW09-AN4215
Abutment screw		Titanium	PW09-RS4208
Ketron 1000 PEEK abutment	Quadrant Engineering Plastic Products, New Brunswick, Canada	Pure Polyetheretherketone	253H08-A 253H08-B
HY-Bond Zinc phosphate cement	SHOFU Inc., Kyoto, Japan	Powder : Zinc Oxide 90%, Magnesium Oxide 10%, Fluorides and Bismuth oxide, Silica Liquid : Phosphoric acid 67%, Aluminum 3%, Water 30%	121701
Temp-Bond™ NE	Kerr Corp, California, USA	Base : Zinc oxide (ZnO) Catalyst : Ortho-ethoxybenzoic acid (EBA), Octanoic acid, Carnauba wax	23335CU
Superbond C&B®	SUN MEDICAL CO.,LTD., Shiga, Japan	Initiator : TBB Monomer : 4-META 5%, MMA 95% Powder : PMMA	ST1
Panavia™ F 2.0	Kuraray Noritake Dental Inc., Tokyo, Japan	Primer A : HEMA, 10-MDP, 5-NMSA Primer B : 5-NMSA, Water, Sodium benzene Paste A : 10-MDP, Silica, Dimethacrylate Paste B : Barium glass, Sodium Fluoride, Dimethacrylate	000060
RelyX™ U200	3M ESPE, St Paul, MN, USA	Base paste: Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers Catalyst paste: Methacrylate monomers, Alkaline (basic) fillers, silanated fillers	6309318
DD Bio Splint P HI (high impact thermoplastic acrylic polymer)	Dental Direkt GmbH, Spenge, Germany	Polymethylmethacrylate	-

Table 1. List of materials, manufacturers and their composition used in this study.

Specimen preparation and cementation

Fifty abutments were placed on each implant analogue and torqued to 30 N·cm. They were cleaned with deionized water for 5 minutes in an ultrasonic machine (Transsonic T700, Elma, Singen, Germany) and stored in a dry place. The abutment screws were covered with cotton pellet and temporary filling material (Cavit, 3M ESPE, Seefeld, Germany) to the level of access hole.

Each crown was cemented with 5 different groups of luting cements, which were ZPC, Temp-Bond™ NE, RelyX™ U200, Panavia™ F 2.0, and Superbond C&B®. It was seated using finger pressure prior to being placed under a constant axial load of 10 N at room temperature and cured according to the manufacturer's recommendations. After that, excess cement was removed with plastic curette before each crown was placed in deionized water for 24 hours at 37°c temperature.

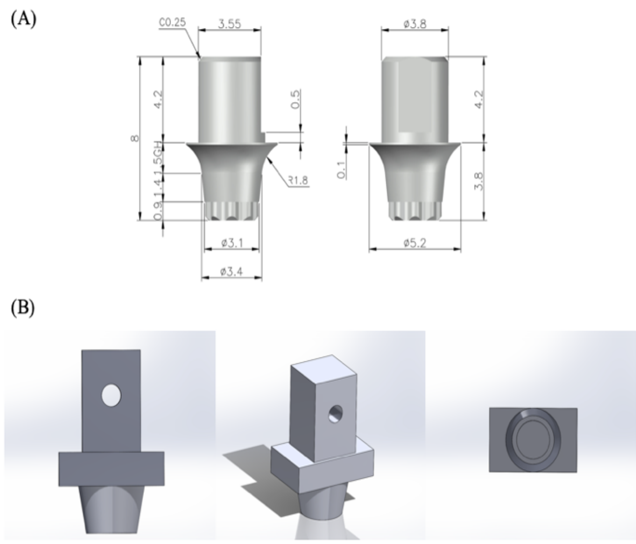

Figure 1. (A) CAD abutment design with precise dimensions in mm., and (B) CAD clear polymethylmethacrylate crown design in SolidWork (version 2018) with 2 mm. hole in the middle for mounting with universal testing machine.

Retention strength measurement

Prior to the measurement, the specimens were placed and mounted parallel to the loading direction of the universal testing machine (Instron® 5566, Norwood, Massachusettes, USA). To analyze the retention, the specimens were subjected to analyze the retention with load cell 10000 N. at crosshead speed 0.5 mm/min. according to Heintze et al.[29] until the debonding of the crowns were determined. The maximum load used to debond a crown from abutment was recorded in Newtons, and subsequent converted to retention strength following Pascal's law (N/mm^2) or Megapascal (MPa). The abutment surface area was 48.54 mm^2, calculated by AutoCAD 2015.

Failure analysis

The debonded abutments were examined with stereomicroscope (OLYMPUS, Japan) at 20x and 56x magnification. The debonding surface was classified into four failure types as follows: 1) Adhesive failure between clear PMMA crown and cement, 2) Cohesive failure within cement, 3) Adhesive failure between cement and PEEK abutment, and 4) Mixed failure.

Statistical analysis

The descriptive statistics for all groups were calculated. The Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test the normality of the data whereas the homogeneity of variances according to Levene statistic showed no significant difference (p>0.05). Since the data were normally distributed, parametric statistics were used to evaluate the retention strength. One-way ANOVA following post-hoc comparisons by Turkey's test were applied for comparisons at a confidence interval of 95%. The statistical analyses were performed with SPSS version 23.0(Chicago, IL, USA). The statistical significance level was set at an alpha level of 0.05.

Results

Surface roughness, topography and EDS analysis

All of the specimens showed the same mean roughness average (Ra) of 0.004 micron which confirms the same surface characteristic of all specimens. The SEM images and EDS analysis are shown in figure 2. The surface area of the PEEK samples was generally smooth as shown in figure 2(A), and predominantly consisting of carbon and oxygen, generally found in structure of PEEK, as seen in figure 2(B).

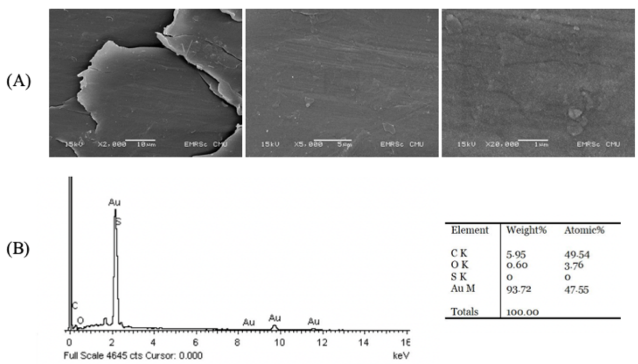

Figure 2. (A) SEM images demonstrating the microstructure of PEEK at 2000x, 5000x and 20,000x magnification, and (B) EDS analysis.

Retention strength test

All abutments in Superbond C&B® group were dislodged from the screw and analogue as shown in figure 3(A). One-way ANOVA revealed a significant difference across the cement groups (p<0.01). The mean retention strength and standard deviations of all groups are demonstrated in figure 3(B).

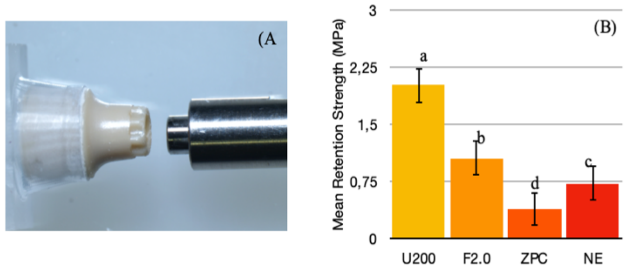

Figure 3. (A) separated screw of the implant-abutment connection in Superbond C&B® group. (B) measured mean retention strength.[a,b,c,d] Significant differences between groups are displayed with different letters ($p < 0.01$).

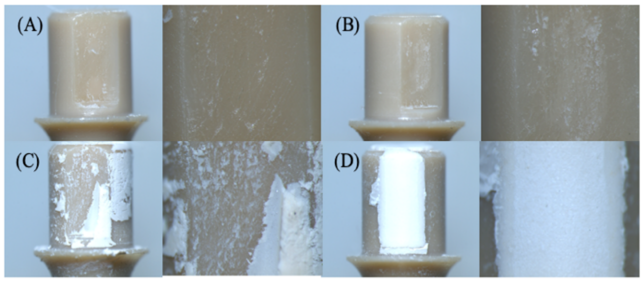

Figure 4. Images of the mixed failure modes at the debonded PEEK abutment surfaces. A: RelyX™ U200 , B: Panavia™ F 2.0, C: Temp-Bond™ NE, and D: Zinc phosphate cement.

RelyX™ U200 showed significantly higher mean retention strength (2.01 ±0.22 MPa) than the others followed by Panavia™ F 2.0 (1.06 ± 0.11 MPa), Temp-Bond™ NE (0.73 ±0.15 MPa) whereas zinc phosphate cement showed the lowest results (0.39 ±0.16 MPa) respectively.

Failure analysis

The percentages of each failure mode are demonstrated in table 2. The observation of failure modes under stereomicroscope at 20x and 56x magnification are shown in figure 4. All of the specimens in each groups exhibited mixed failure mode except the Superbond C&B® group.

Group	Types of Cement	Mode of failure			
		Adhesive failure between clear PMMA crown and cement	Cohesive failure within cement	Adhesive failure between cement and PEEK abutment	Mixed failure
1	Zinc phosphate cement	0	0	0	100
2	Temp-Bond™ NE	0	0	0	100
3	RelyX™ U200	0	0	0	100
4	Panavia™ F 2.0	0	0	0	100
5	Superbond C&B®	-	-	-	-

Table 2. Percentage of each failure mode in different types of cement.

Discussion

This in vitro study was investigated due to the insufficiency of reliable information about cement selection for PEEK abutment and PMMA crown. The null hypothesis was rejected due to the fact that each type of cement demonstrated different retention strength of PEEK abutment and PMMA crown.

Despite the fact that the retention values were not obtained from the test in Superbond C&B® group, which was the only MMA-based resin cement in this study, the force exceeded the maximum elasticity tolerance of the PEEK abutment connection. It could be inferred that the retention strength was the highest among experimental groups. The explanation for these findings may be related to the MMA monomer which had influence on both PMMA crown and PEEK abutment. The former was wet by the monomer which may have caused swelling and dissolving of the surface. Thus, the secondary interpenetrating polymer network (IPN) bonding between the PMMA-based resin cement and PMMA crown took place.[33, 34] Considering the latter surface, a study by Schmidlin reported that MMA caused the PEEK to swell but only MMA could not perform sufficient bonding property.[35] In previous studies, using Visio.link adhesive that composed of MMA, and Pentaerythritol triacrylate (PETIA) showed durable tensile bond properties between PEEK and resin composite even after aging simulation.[36-39] In this study, the PEEK surface was also swelled by MMA and the 4-META functional group in Superbond C&B® corresponded the connection to the resin with two binding sites of phthalic anhydride.[35,40] Furthermore, Stawarczyk et al and Uhrenbacher et al recommended using air abrasion with MMA-containing adhesives for the highest tensile bond strength.[40,41]

It could also be inferred that both DMA-based resin cements showed lower bond strength compared to Superbond C&B®. Our results are in agreement with the studies of Kern et al, Kuel et al and Stawarczyk et al that air abrasion combined with 10-MDP in adhesives showed low tensile bond strength to resin composite compared to MMA.[36, 37, 42]

Furthermore, the use of Ambarino P60 adhesives in the study of Uhrenbacher et al, which contains phosphoric acid ester combined with DMA, resulted in minimal retention strengths. This could be evidence that any functional groups cannot further chemically react to PEEK without MMA monomers.[40]

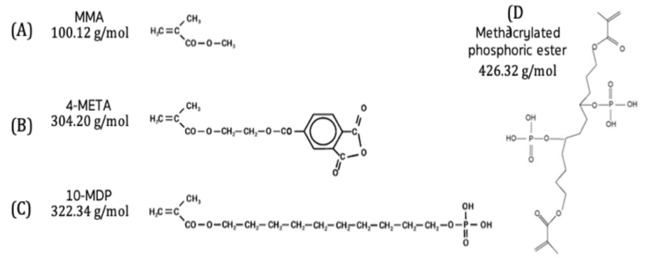

Figure 5. Showed molecular weight and structure of (A) 4-META (B) MMA (C) 10-MDP (D) Methacrylated phosphoric ester.

Not only do the solvents of the adhesive system or resin cement play important roles in creating a bond to PEEK but also functional molecules. The difference of molecular weight and viscosity of the cements could affect the diffusion, penetration and mechanical properties. Martin et al and Nunes et al reported that large molecular weight and size of the molecule were the important factors that improve the bond strength.[43, 44] On the other hand, a low molecular weight with a small size may have a greater chance to penetrate and interact with surfaces of the substrate.[45] The small molecule of MMA in Superbond C&B®, as shown in figure 5, penetrated easily on the surfaces while the large molecule of 4-META was responsible for the connection as mention earlier. Comparing between two DMA-based resin cements, RelyX™ U200 showed a the higher bond strength than Panavia™ F 2.0. RelyX™ U200 compose of methacrylated phosphoric ester, larger in size and weight, as a functional group while Panavia™ F 2.0 is composed of 10-MDP. Another reason was that the methacrylated phosphoric ester molecule has two phosphate groups while 10-MDP has only one phosphate group to react with other substrates.

Considering viscosity, it was influenced by the amount and size of any fillers, added to improve the strength of cement. The highest filler content is Panavia™ F 2.0 (more than 75%wt) followed by RelyX™ U200 (72%wt) and Superbond C&B®(unfilled), which was found after mixing the cement following the instruction from manufacturer.[46] So Panavia™ F 2.0 might exhibit the worst adaptation to PEEK surface due to its' high viscosity.

Zinc phospate cement, used as a gold standard and control group of cements in many studies, showed remarkably lower retention strength than Temp-Bond™ NE.[26] In previous studies using metal abutment, zinc phosphate showed higher retention values than temporary cements, which was adverse from our results.[47, 48] There were many reasons why ZPC revealed lower tensile bond strength. The first is that materials with low elastic modulus showed a high degree of debonding when used with conventional cements.[29] The second reason was the brittle property of ZPC.[49] Another issue was the mismatch of selected cement space, 50 micron in this study, and the proper film thickness of ZPC, which is 25 micron according to ADA Specification No.8. Flanagan reported that the thicker film thickness of ZPC exhibited in lower functional property of the cement.[50] The last reason was that ZPC wasn't completely stable at the time of the test, 24 hours after cementation. According to Arnold, ZPC is amorphous within first 48 hours, and mainly composed of unreacted zinc oxide and phosphoric acid. On the other hand, older cements were more chemically stable.[51] However, ZPC and Temp-Bond™ NE certainly showed minimal retention for use in clinical situations and may cause patient dissatisfaction.

Furthermore, no adhesive failure types were observed. Most of the failure types between the PEEK abutments and PMMA crown were mixed failure, showing that the adhesion of cement to PMMA may be as poor as cement to PEEK. Consequently, both of the surfaces have to be improved in bonding efficacy.

Regarding clinical application, the minimum acceptable bond strength of resin-based material according to ISO10477 is 5 MPa.[52] Furthermore, it has been reported that 10-12 MPa should be required to gain long-term durability in oral condition.[38] Surface pretreatments and bonding agents may be required to improve the bond strength to reach the acceptable values. Consequently, combining both mechanical or chemical pretreatment (e.g. sulfuric etching and air abrasion) with adhesives or resin cement that consists of both MMA and any other large functional molecules has been suggested for higher bond strength.[53]

In this study, a specific mounting metal instrument was milled and used in aligning the specimens to the upper member of the machine. The instrument prevented the undesired, non-axial, and unequal distribution force that can twist the crown from its' own abutment while mounting. If the circumstance had occurred, the cement would break prior to the test. Using clear PMMA as a crown material can ensure seating of the crown but may not simulate the polymerization performance of dual-curing resin cement or any less transparent material used in real clinical situations. The thermocycling, which usually used to simulate clinical degradation over time, was not applied. This was assumed to have no influence on the results as long as the specimens were studied with the same protocol.[29]

Further investigations are necessary to gain more suitable protocol and durable bonding stability for long-term clinical implementation. The PEEK abutment over titanium connection or filler-reinforced-PEEK was suggested to avoid the breakage of the abutment connection, as seen in Superbond C&B® group.

Conclusions

Within the limitation of this in vitro study, these conclusions are drawn

1) The Superbond C&B® exhibited the highest retention strength in bonding PEEK abutment to PMMA crown.

2) The RelyX™ U200 , Panavia™ F 2.0, zinc phosphate cement, and Temp-Bond™ NE failed to provide sufficient retention strength in bonding PEEK abutment to PMMA crown.

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Declaration of Interest

The authors report no conflict of interest.

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