Optimal Design of PEEK CAD/CAM Fabricated Orthodontic Fixed Lingual Retainer

[1] Dr. Riyadh Abdulhamza Ruwiaee, [2] Prof. Dr. Akram Faisal Alhuwaizi


ABSTRACT
Objective: PEEK CAD/CAM retainers can now be bonded onto teeth to create a flexible, biocompatible, and more anatomically adapted retainer. The aim of the present study was to optimize the design of PEEK retainers.

Material and methods: The PEEK sample composed of 12 pads (half of which had a central hole) and 18 mini-retainers each composed of 2 pads joined by a connector of varying pad sizes (3x4mm and 2.5x3.5mm) and connector heights (2mm and 1.5mm). They were treated by 98% sulfuric acid for 1 minute followed by Single Bond Universal and adhered to the lingual surface of premolar teeth by 3M Transbond™ System. Then shear bond strength (SBS) was tested using a Universal Testing Machine and the data was analyzed using t-test for independent samples.

Results: PEEK pads with a hole showed significantly higher SBS than without a hole. For the mini-retainers, the larger pad design showed only a marginally higher SBS than with the smaller pads, while the 2mm connector gave a significantly higher SBS than the 1.5mm group.

Conclusion: The optimal PEEK lingual retainer design includes 3x4mm pads with a central hole joined by a 2mm high connector.

Keywords: PEEK lingual retainer, design

INTRODUCTION
In orthodontics, although the patient may feel that treatment is complete when the appliances are removed, an important stage lies ahead.1 Nowadays, there is a strong acceptance that a retention phase is an integral and crucial phase following all types of active orthodontic treatment for stability of treatment results. Furthermore, lifelong retention is advised in some cases.2 As there are many types of retainers, the fixed lingual retainer was the one recommended by the orthodontist to fit a specific situation.3 Fixed retainers have a number of advantages, such as better aesthetics and minimal patient cooperation.4 However, the disharmony between retainer wire and tooth surface, errors in wire placement or bonding technique and mechanical properties of retainer wires play an important role in failure of fixed retainers.5
the unexpected torque movements, the failure rate of metal retainers is 3.5%–53%, whereas this rate changes to 11% - 51% for fiber retainers. It is reported that passive adaptation of retainer, avoiding saliva contamination, and preventing biting hard foods increases the success rate of fixed retainers. Various types of retainers have been described with wires of differing materials, properties and diameters, or using different types of composites for the adhesion or with fiber reinforcement. In recent years, bonded retainers have been manufactured using CAD–CAM systems. The studies in this area are limited as this is a very new technology. The techniques and types of wires used for manufacturing bonded retainers using CAD–CAM technology vary for each firm. Two recent articles reported the fabrication of a custom lingual retainer cut from a nickel-titanium block with CAD/CAM technology and a CAD/CAM Zirconium bar as a bonded mandibular fixed retainer. Alternatively, a new type of retainer, digitally manufactured in PEEK material using CAD CAM system, can now be bonded onto teeth to create a strong, durable, tooth-colored flexible, biocompatible, and more anatomically adapted retainer. This organic thermopressed polymer known as polyetheretherketone (PEEK), is a colorless material now widely used in engineering, medical and dental applications. PEEK has excellent chemical and mechanical resistance properties, even at higher temperature. It shows a high resistance to biodegradation and damage in organic and aqueous environments. It has a high tensile strength and an elastic modulus. Recent PEEK can be seen as a shape-memory polymer. This exciting material is giving a high-strength appliance in white shades to allow passive retention of anterior teeth.

However, the optimal design of these new PEEK fixed lingual retainers is not clear. Therefore, the objective of this study was the optimization of the design of a new PEEK CAD/CAM fabricated fixed lingual retainer using CAD/CAM technology and milled PEEK as alternative material for fixed orthodontic retention.

Material and methods

To mimic the anterior part of the lower dental arch, 6 premolars were matched with each other to form contact areas. To simulate the mesiodistal width of lower central incisors, the proximal surface of the premolars was reduced to 6 mm. For standardization purposes, the buccal surface was phosphoric acid etched, washed with water, and dried to a chalky white appearance. An adhesive primer was applied to the etched surface, and lower central brackets were bonded with Transbond XT (3M Unitek, Monrovia, CA, USA) and then light-cured for a total of 20 seconds. The teeth were then ligated by ligature elastics to 6cm length of a .021x.025 heavy gauge archwire inserted in plastic sticks with equal dimension on both sides. Next, acrylic was poured in the plastic mold so that the long axis of the teeth was perpendicular to the base of the mold (Figure 1). This procedure was repeated to fabricate eight molds.

The teeth model was digitized using Smart optic digital scanner to create a file of virtual model which was uploaded to the lab and opened using the exocad software system in order to design a virtual PEEK retainer. Thus, the final design of each PEEK retainer had 6 pads and 5 connectors. The design was made with supports on the occlusal surfaces of the teeth to allow an easier seating with high accuracy. Moreover, the design thickness was 0.8mm (Figure 2).
Once the virtual design of retainer was complete, it was sent to CORITEC 250i CAD/CAM system milling engine (Imes-Icore GmbH, Leibozgraben, Germany) loaded by blank of dental PEEK to create the final PEEK retainer. PEEK retainers were made with smooth, polished surfaces and fitted passively on the lingual surfaces of the premolars with guidance of occlusal support (Figure 3).

Two retainers were milled with pads 3mm wide and 4mm high (12mm² surface area). A 1mm wide hole was drilled in the middle of each of the six pads of one retainer to compare it with a non-perforated retainer. Both of the retainers were treated with 98% sulfuric acid for 60 seconds, then rinsed off with distilled water for 60 seconds and dried with oil-free compressed air. Then the pads were conditioned using Single Bond Universal (3M ESPE, Deutschland GmbH, Germany) by applying a thin layer with rubbing for 20 seconds, gentle air stream for 5 seconds and then light curing for 10 seconds.

The lingual surfaces of the premolars were cleaned with oil free pumice using a prophylaxis brush for 20 seconds, rinsed with distilled water, and air-dried. Then the enamel surfaces were etched with 35% phosphoric acid for 30 seconds, rinsed with distilled water, and dried for 15 second. Then, Transbond XT primer was uniformly applied to the enamel surface using a microbrush, gently air-blown, and photo polymerized for 20 seconds on each tooth surface with an LED polymerization lamp. Next, Transbond™ LR adhesive was applied to the PEEK pad base, and then the pad base was placed onto the enamel surface and pressed with an equal force. The retainer occlusal supports allowed an easier seating of the design with high accuracy. After careful removal of the excess adhesive, the teeth were light-cured for a total of 40 seconds at the mesial and distal sides for 20 seconds each.

After retainer bonding, occlusal rests and connectors were cut using high speed fissure turbine bur leaving six separated pads. The specimens were stored in distilled water for 24 hours at 37°C before SBS test. SBS of each group was tested with a Universal Testing Machine. The specimens were fixed with a special fixture. The loading piston was closed to the bonding surface. The load was applied with a crosshead speed of 0.5 mm/min with the bonding surface parallel to the loading piston. SBS testing was done and the results were compared with those without hole (Figure 4).

Six extra PEEK retainers were milled; two retainers with 3mm x 4mm pads and 1.5mm high connectors, two retainers with 2.5mm x 3.5mm pads and 1.5mm high connectors, and two retainers with 3mm x 4mm pads and 2mm high connectors. In each pad a hole may be drilled as outlined before depending on the results of previous test. After bonding, each retainer was cut into 3 pieces of 2 pads joined by a connector so that each group consisted of 6 mini retainers.

During SBS test, the occluso-gingival load was applied vertically to the center of the interdental PEEK mini connector between the two teeth using a plunger attached to the Instron universal testing machine at a loading speed of 0.5 mm/min until bond failure occurred (Figure 4). The results of the groups were then compared to examine the effect of surface area and connector height.
Figure 1: Teeth model preparation; (A) Teeth matched, (B) Teeth ligated, (C) Teeth hanged vertically within molded, and (D) Teeth embedded in acrylic.

Figure 2: A virtual PEEK retainer: (A) surface area and thickness PEEK pad, (B) Connector height, (C) Occlusal support, and (D) Connector thickness.
Figure 3: A final PEEK retainer: (A) before milling, (B) after milling, and (C) smooth polished surfaces of final actual retainer.

Figure 4: SBS test of PEEK pads and mini-retainers.
Statistical analysis

The SPSS statistical software version 22.0 for window (SPSS version 22, IBM, Armonk, NY, USA) was used for statistical analysis. The Shapiro-Wilk test was performed to verify the normality of SBS (Shear bond strength) data distribution. While the one-way analysis of variance (ANOVA) and post-hoc Tukey’s test was used to examine the interactions of the two factors on SBS.

Results

Adding a hole gave significantly higher SBS (33.958 MPa) than the PEEK pads without a hole (30.417 MPa) ($t=4.259$, d.f.=10, $p=0.002$) (Figure 5). Therefore, all coming retainers were perforated. When lingual retainers with two pads and a 1.5mm high connector were tested, the large pads (3x4 mm) gave slightly higher SBS than the small pads (2.5x3.5 mm). However, independent sample t-test indicated that the difference was statistically not significantly ($t=-1.437$, d.f.=10, $p=0.181$). However, when large pad mini retainers were tested, wider connectors (2mm) gave significantly higher SBS than narrower connector (1.5mm) ($t=12.153$, d.f.=10, $p=0.000$) (Figure 6).

Figure 5: Mean SBS (± SD) of PEEK pad with and without hole.
Figure 6: Mean SBS of PEEK mini retainers with varying pad sizes and connector heights

**Discussion**

Previous PEEK lingual retainer studies used bovine teeth while in this study human teeth were used to be more clinically relevant. Premolars were selected because of the scarcity of lower incisors.

All specimens were bonded by Single Bond Universal after exposing to 98% sulfuric acid for one minute. This technique was shown to give the highest SBS.

During SBS testing a vertical force was applied at the midpoint of the connector of the PEEK mini retainer which was bonded to a pair of teeth embedded in a resin block. This is similar to previous studies who worked on lingual fixed retainer made of metal or PEEK.

To the author knowledge, no previous study has reported adding a hole to the PEEK pad retainer in attempt to increase SBS. The PEEK pad with hole design showed significantly higher SBS (33.95 MPa) than the regular design with no hole (30.417 MPa). This may be attribute to:

- the hole acts as an anchor for the resin material
- the hole allows for the escape of excess resin material giving a thin resin layer
- the hole allows the curing light to penetrate deeper in the resin increasing the degree of conversion of the resin monomer even with low light intensity.
Despite various studies on the bonding strength of fixed retainers, the exact magnitude of bonding strength sufficient for lingual fixed retainers remains unknown. Many studies regarding fixed lingual retainers were focused on the effect of wires and resin types, while little is known regarding the effect of the surface area of resin on detachment force.18

Bearn et al.19 using multistrand lingual wire concluded that resin composite 1mm in thickness provided the optimal combination of maximal strength (71.8 N) and minimal bulk. While, our PEEK pad was only 0.8 mm thick and gave higher SBS using the appropriate bonding protocol. Zachrisson,13 stated that the 0.8 thickness of milled PEEK allows us to have a thin and comfortable appliance and still have some physiological movement of the teeth. Moreover, PEEK retainer is lightweight with no nickel sensitivity and less resin toxicity in comparison to traditional metal frameworks.

Lee et al.18 found that the force required to detach the wire from the bonding resin increased as the surface area of resin increased with highest SBS being 102.38 N for 16 mm² resin surface area. Although increasing the amount of resin on lingual wire fixation may help to enhance the bond strength, there are several side effects, such as tongue discomfort, increased vulnerability to periodontal diseases, decreased wire distance which in turn will affect the physiologic movement of the retained teeth.

When this study used smaller surface area (8.75 mm²) and thinner PEEK pad (0.8 mm) higher SBS (186 N) was obtained than the previous study which points out the superiority of the pad retainer design over the wire retainer design. Also, the difference between the large and small pad designs was statistically insignificant because the failure mode differed between the designs being at the enamel/PEEK interface of the small pad design and due to fracture of the connector in large pad design. This indicates that the use of large pads gave no superiority to small pads.

Importantly, Shaughnessy et al.20 stated that the fixed retainers can produce inadvertent tooth movement especially torque. Therefore, the rectangular geometrical shape of PEEK retainer pads and connector resist relapse and are less likely to break because of the combination of both flexibility and durability of PEEK material, and are effective in maintaining the alignment of the anterior teeth due to chemical and mechanical resistance to distort by function or oral fluid as well as being passive when bonded.

However, 2mm high connector design showed a significant larger SBS than the 1.5mm high connector design. It is impractical to fit this higher connector with the small pad design, so it is recommended to use the larger pad and higher connector design in patients with larger teeth.

**Limitations of the study:**

The study was carried out on reshaped premolars; which means that they did not mimic exactly the shape of the lower incisors, nor the shape of the lower dental arch curvature. However, the size of the pads and connectors a custom design for each patient and the proposed design in this study can only serve as a general guideline. The results of this study apply to the use of pure unfilled PEEK. However, if the stiffer
filled PEEK is chosen to construct the lingual fixed retainer different SBS values may be found.

**Conclusion:**

Within the scope of the study, to increase the SBS of PEEK lingual retainers to the teeth, a central hole can be added to the pads. Also, larger pads and connectors are advised, however the real dimensions in the clinical setup depend on the size of the teeth.

**REFERENCES**


