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In Vitro Comparative Evaluation Of Tensile Bond Strength Of PEEK Restorations In Short Crowns With And Without Grooves And Endocrowns

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Abstract
Background: *Polyetheretherketone (PEEK) has emerged as a promising biomaterial in prosthodontics due to its favorable mechanical and biological properties. However, its bonding behavior with different preparation designs remains under investigation.*
Aim*: To comparatively evaluate the tensile bond strength of PEEK restorations in short crowns with grooves, without grooves, and endocrowns.*
Materials and Methods*: Thirty caries-free molars were divided into three groups (n=10): short crowns without grooves (SC), short crowns with grooves (SCG), and short endocrowns (SE). Standardized tooth preparation, CAD-CAM fabrication of PEEK copings, surface treatment, and cementation using resin cement were performed. Tensile bond strength was assessed using a universal testing machine. Statistical analysis was performed using one-way ANOVA and Tukey post hoc test.*
Results*: The highest mean tensile bond strength was observed in SC (146.37±23.31 N), followed by SE (109.72±15.23 N), and SCG (95.57±29.01 N). Differences between groups were statistically significant (p=0.000).*
Conclusion*: Short crowns without grooves exhibited superior tensile bond strength. Incorporation of grooves did not enhance bonding in short clinical crowns. Endocrowns showed intermediate performance due to circumferential enamel bonding.*

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I. Introduction

The persistent evolution of dental biomaterials is driven by the clinical need for substances that harmonize mechanical durability with biological compatibility. Despite significant research efforts, an "ideal" material that fulfills every clinical requirement remains elusive, prompting ongoing investigation into advanced polymers and specialized fabrication methods.[1,2] Among these, Polyetheretherketone (PEEK) has emerged as a prominent high-performance thermoplastic. A semi-crystalline, linear polycyclic aromatic polymer, PEEK is characterized by its chemical structure consisting of aryl rings linked by ketone and ether functional groups.[3]

PEEK's clinical appeal is rooted in its unique physical profile. It exhibits high resistance to hydrolysis, thermal stability, and a low density that favors patient comfort. Most notably, its modulus of elasticity (approximately 3.6 GPa) is significantly lower than traditional metal alloys or zirconia, closely mimicking the biomechanical behavior of human bone.[3,4] This "bone-like" elasticity allows PEEK to act as a stress-breaker, potentially reducing the transmission of damaging forces to the underlying tooth structure or implants. Furthermore, as a metal-free material, it eliminates the risk of galvanic corrosion and metal-related allergic reactions, while offering excellent biocompatibility without evidence of cytotoxicity or mutagenicity.[4]

A recurring challenge in restorative dentistry is the management of short clinical crowns, where the vertical height is insufficient to provide adequate traditional retention and resistance form. In such cases, the preparation's geometry often fails to prevent the displacement of the restoration under functional loads. While classical prosthodontic literature suggests that auxiliary features—such as proximal grooves or boxes—can enhance mechanical retention by limiting the path of withdrawal, their efficacy in the context of modern adhesive dentistry and short preparations remains a subject of debate.[5,6] Some evidence suggests that these features may inadvertently compromise the bond by reducing the available surface area of enamel, which is a more predictable substrate for resin adhesion than dentin.[7,8]

Concurrently, the "endocrown" design has gained traction as a conservative alternative for endodontically treated teeth with limited clinical height. By utilizing the pulp chamber for macromechanical retention and relying on a wide peripheral enamel seal, endocrowns offer a different mechanical approach to the "short crown" dilemma.[1,9] Given the increasing integration of CAD-CAM technology, PEEK restorations can now be milled with high precision to fit these complex geometries.[3] However, there is a lack of comparative data regarding how PEEK performs in these varying preparation designs. This study aims to evaluate and compare the tensile bond strength of PEEK restorations in three specific configurations: short crowns with grooves, short crowns without grooves, and endocrown designs.

II. Materials And Methods

Specimen Selection and Preparation

Thirty human mandibular molars, extracted for periodontal reasons and characterized by similar crown sizes, were selected for this study. The inclusion criteria required the teeth to be caries-free, without previous restorations, and possessing complete root formation. Following extraction, any remaining soft tissue or calculus was removed using a periodontal scaler, and the specimens were stored in distilled water at room temperature to prevent dehydration. Each tooth was then embedded in self-cure acrylic resin within PVC tubes (20 mm diameter, 20 mm height) up to the cemento-enamel junction (CEJ) to ensure a stable base for testing.

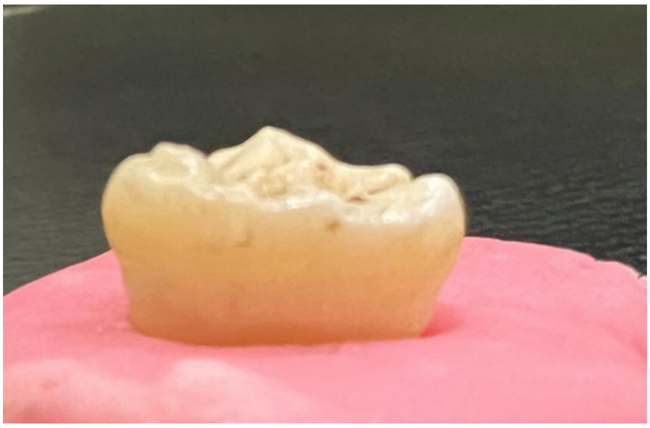


Fig. 1- Tooth Embedded till CEJ

Experimental Grouping

The specimens were randomly assigned into three distinct experimental groups (n=10 per group) based on the preparation design:

- **Group SC:** Short clinical crown without grooves.
- **Group SCG:** Short clinical crown with auxiliary mesial and distal grooves.
- **Group SE:** Short clinical crown prepared for an endocrown restoration.

Standardized Tooth Preparation

To simulate a short clinical crown scenario, all thirty teeth underwent an anatomical occlusal reduction to a height of 3.5 mm above the CEJ using a carborundum disc under continuous water cooling.

- **Groups SC and SCG:** These specimens were prepared with a high-speed handpiece and diamond burs to achieve a 1 mm chamfer finish line and a 20° total occlusal convergence (taper). For Group SCG, auxiliary retention was added in the form of two grooves (one mesial and one distal) with a depth of 0.3 mm and a height of 2.5 mm.
- **Group SE:** For the endocrown group, the pulp chamber served as the cavity for macromechanical retention. An access cavity was prepared with a length of 5 mm and a depth of 2 mm, featuring a 7° occlusal taper to facilitate the path of insertion.

Figure 2. a: Showing Short Clinical Crown With Grooves

Figure 2. b: Showing Short crowns without groove

Figure 2. c: Showing Endocrowns

Digital Workflow and CAD-CAM Fabrication

The prepared teeth were dried and scanned using a high-resolution Medit Lab Scanner. The resulting STL files were imported into Exocad software for the design of the restorations. PEEK copings (BioHPP, Bredent) were designed with a standardized thickness. A specific 4x4 mm attachment was designed on the occlusal surface of each coping to allow for the attachment of the Universal Testing Machine's jig during the pull-off test. The designs were then milled using a CAD-CAM unit to ensure high precision and marginal fit.

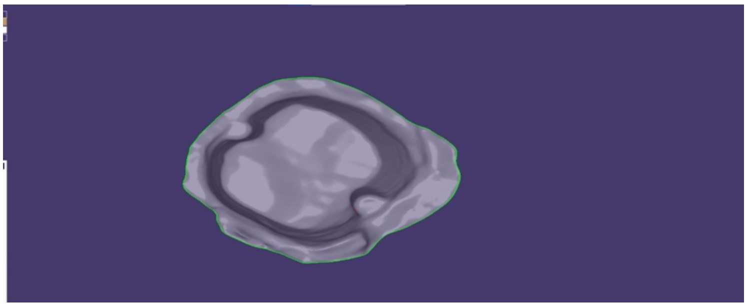


Figure 3. a. (i): Exocad Scanner Showing Tooth With Grooves

Figure 3. a. (ii): Exocad Scanner showing design of coping

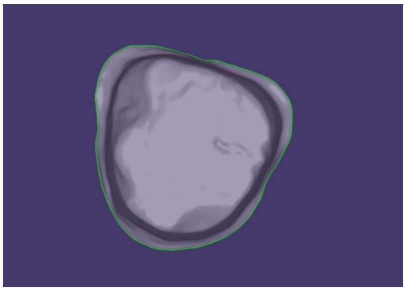


Figure 3. a. (ii): Exocad Scanner showing design of coping

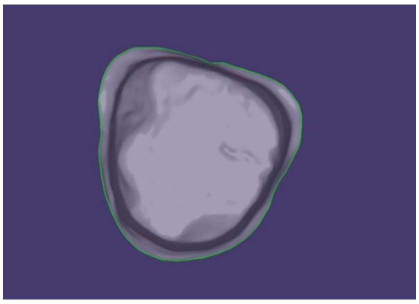


Figure 3. b. (i): Exocad Scanner Showing Without Grooves

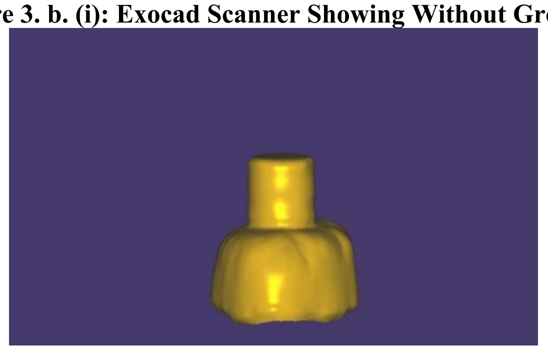


Figure 3. b. (ii): Exocad Scanner showing design of coping

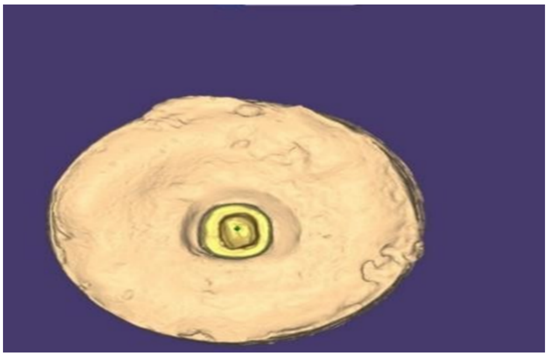


Figure 3. c. (i): Exocad scanner showing endocrowns

Figure 3. c. (ii): Exocad scanner showing design of coping

Surface Treatment and Adhesive Protocol

The internal surfaces of the milled PEEK copings were subjected to a standardized conditioning protocol. They were air-abraded with 70 µm Al_2O_3 particles at a pressure of 0.2 MPa for 10 seconds at a distance of 10 mm. Following air-abrasion, the surfaces were cleaned and a Visiolink adhesive primer (Bredent) was applied to the bonding surface and light-cured for 90 seconds.

Cementation Procedure

The tooth preparations were cleaned and dried. RelyX U200 (3M ESPE) self-adhesive resin cement was applied to the internal surface of the copings. Each restoration was seated on its respective preparation and held under a constant, customized 5 kg load for 10 minutes to ensure a uniform cement film thickness and standardized seating pressure. Any excess cement was removed prior to the final set.

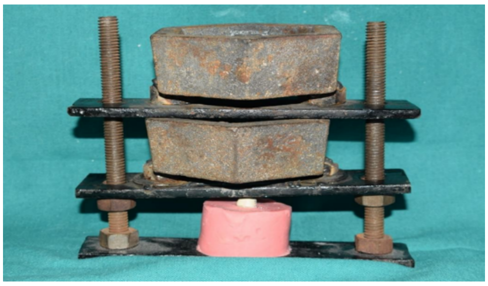


Fig. 4 Customized Load Of 5kgs

Tensile Bond Strength Testing

After 48 hours of storage, the specimens were mounted in a Universal Testing Machine (ACME Engineers). A tensile load was applied to the occlusal attachment at a crosshead speed of 1 mm/min. The force required to cause debonding was recorded in Newtons (N) for each specimen.

Fig. 5: Universal Testing Machine

III. Results

The maximum load required to break the bond between The PEEK coping and short crowns containing grooves (SCG) for each of 10 samples in Group 1 was tabulated in **Table 1 and Graph 1**.The mean value of load was found to be 95.57 N.

The maximum load required to break the bond between The PEEK coping and short crowns without grooves (SC) for each of 10 samples in Group1was tabulated in **Table 2 and graph**
The mean value of load was found to be 146.37N

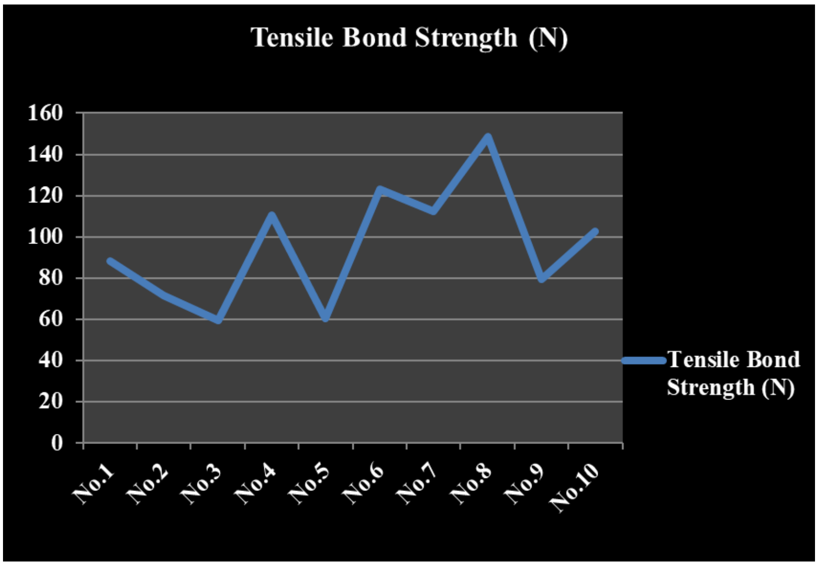
The maximum load required to break the bond between The PEEK coping and short endo crowns (SE) for each of 10 samples in Group1was tabulated in **Table 3 and graph**
The mean value of load was found to be 109.72N.

Table 4 and Graph 4 shows the mean tensile bond strength of three groups i.e. short crown with grooves, crown without grooves and endo-crown. The result showed that crown without grooves showed highest tensile bond strength with mean value of **146.37±23.31**while short crown with grooves showed lowest mean tensile bond strength with mean value of **95.57±29.01.**

Table 5 shows the comparison of mean tensile bond strength between small crown with grooves, crown without grooves and endo-crown. The Level of Significance in the differences of mean values was determined by one way ANOVA test. There was highly significant statistical significant difference observed between all the groups (F value:-12.419 p value=0.000). Inter group comparison also showed highly significant difference between all the three groups.

Table 1: Descriptive statistics showing Tensile bond strength of Group1 i.e. Short Crown with Grooves

Sr. No.	Sample No.	Tensile Bond Strength (N)
1	No.1	88.10
2	No.2	71.30
3	No.3	59.50
4	No.4	110.50
5	No.5	60.20
6	No.6	123.10
7	No.7	112.40
8	No.8	148.60
9	No.9	79.50
10	No.10	102.50
MEAN		**95.57**

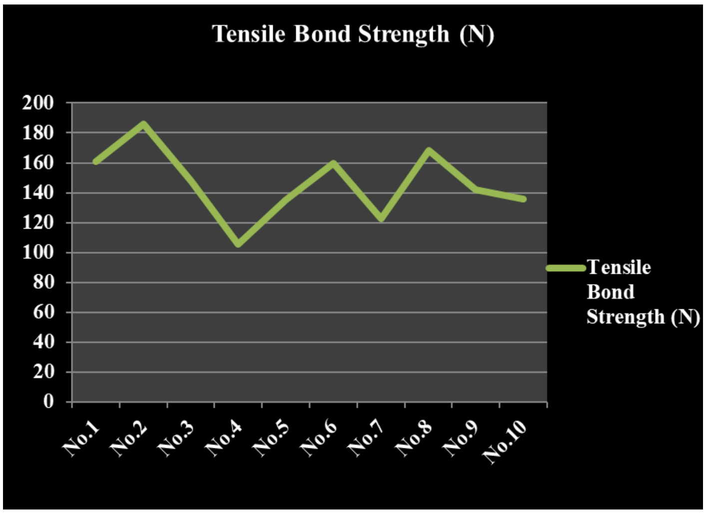


Graph 1:- Graph showing descriptive statistics showing tensile bond strength of Group 1 i.e. Short Crown with Grooves where X axis depicts the number of samples and Y axis depicts the value of tensile bond strength

Table 1 and Graph 1 illustrate Tensile bond strength of Short crown with grooves fabricated using poly etherther ketone. It showed the mean bond strength of 95.57 in 10 samples taken.

Table 2:- Descriptive statistics showing Tensile bond strength of Group 2 i.e. Crown without Grooves

Sr. No.	Sample No.	Tensile Bond Strength (N)
1	No.1	160.90
2	No.2	185.80
3	No.3	147.50
4	No.4	105.60
5	No.5	135.30
6	No.6	159.50
7	No.7	122.70
8	No.8	168.30
9	No.9	142.20
10	No.10	135.90
MEAN		**146.37**

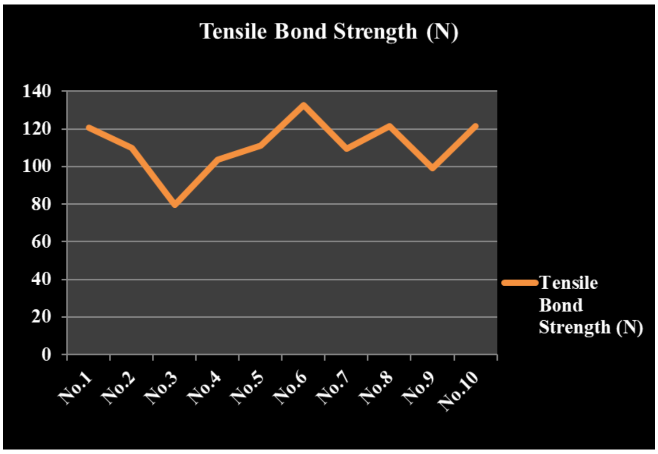


Graph 2: Graph showing descriptive statistics showing Tensile bond strength of Group 2 i.e. Crown without Grooves

Table 2 and Graph 2 shows the Tensile bond strength of crowns without grooves using poly etherther ketone. It showed the mean bond strength of 147.53 in 10 samples taken.

Table 3: Descriptive statistics showing Tensile bond strength of Group 3 i.e. Endocrown

Sr. No.	Sample No.	Tensile Bond Strength (N)
1	No.1	120.50
2	No.2	110.00
3	No.3	79.50
4	No.4	103.50
5	No.5	111.30
6	No.6	132.70
7	No.7	109.50
8	No.8	121.60
9	No.9	98.90
10	No.10	121.50
MEAN		**109.72**

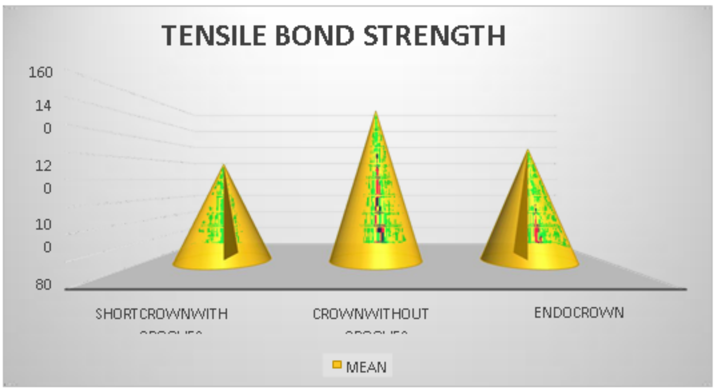


Graph 3:- Graph showing descriptive statistics showing Tensile bond strength of Group 3 i.e. Endo crown

Table 3 and Graph 3 shows the Tensile bond strength of Endo-crowns using poly etherther ketone. It showed the mean bond strength of 109.72 in 10 samples taken.

Table 4: Descriptive statistics showing Mean ±Standard Deviation of all 3 groups

Groups	Frequency	Mean	Standard Deviation
Short Crown with Grooves	**10**	**95.57**	**29.01**
Crown Without Grooves	**10**	**146.37**	**23.31**
Endo crown	**10**	**109.72**	**15.23**
Total	**30**	**117.48**	**31.63**



Graph 4:-Graph showing mean Tensile bond strength of all the 3 groups.

Table 4 and Graph 4 shows the mean tensile bond strength of three groups i.e. short crown with grooves, crown without grooves and endo-crown. The result showed that crown without grooves showed highest tensile bond strength with mean value of **146.37±23.31** while short crown with grooves showed lowest mean tensile bond strength with mean value of **95.57±29.01.**

Table 5:-Comparison between tensile strength of 3 groups

Groups	Mean± Standard Deviation	F-value	p-value
Short Crown with Grooves	95.57±29.01	12.419	0.000
Crown Without Grooves	146.37±23.31		
Endo crown	109.72±15.23		

Post hoc test-Tukey HSD

Dependent variable	Comparison variable	Difference	Sig.	95%Confidence Interval	
				Lower Bound	Upper Bound
Short Crown with Grooves	Crown Without Grooves	-50.80	0.000	-76.89	-24.71
	Endo-crown	-14.15	0.401	-40.95	12.65
Crown Without Grooves	Short Crown with Grooves	50.80	0.000	24.71	76.88
	Endo-crown	36.64	0.006	9.84	63.45
Endo-crown	Short Crown with Grooves	14.15	0.401	12.65	40.95
	Crown Without Grooves	-36.64	0.006	-63.45	-09.84

Table 5 shows the comparison of mean tensile bond strength between small crown with grooves, crown without grooves and endo-crown.. There was highly significant statistical significant difference observed between all the groups (F value:- 12.419 p value= 0.000). Intergroup comparison also showed highly significant difference between all the three groups.

IV. Discussion

In this study, tensile bond strength between 3 groups that is short crown with grooves, short crown without grooves and short endo crown using PEEK material was evaluated. According to this study the highest mean tensile bond strength was found be of group 2: SC (146.37). The second highest mean tensile bond strength was of group 3: SE (109.72). The lowestmean tensile bond strength was found of group 1 : SCG (95.57) (Table 1,2 and 3)

In this study natural teeth were used because they are the most representative of the clinical situation in terms of morphology, architecture, size and bonding properties supporting adhesive restorations. Mandibular 1st molar teethwith average similar dimensions were used due to the very limited supply of many acceptable natural molar teeth of nearly the same dimensions without a single defect and with the exact criteria. So there was a necessity to discard many teeth for selection standardization. PEEK is a biocompatible engineering thermoplastic with unique material properties that make it an attractive material in dentistry[(10)].

A modified PEEK material containing 20% ceramic fillers (BioHPP; Bredent GmbH) has good mechanical properties and excellent biocompatibility[(11-13)]. It can be used for the fabrication of prostheses either by injection moulding or CAD-CAM procedures. The advantages of using this material are the elimination of allergic reactions, good wear resistance, good polishing properties, and low plaque affinity .

Dual cure resin cements are used for the cementation of PEEK materials. One of the main disadvantages of PEEK material in prosthetic dentistry is the low surface energy. PEEK shows low bonding to resin cements[(14)]. One of the main reasons for the loss of cement bonding is the high flexibility modulus of metal substructures and another is the negative stress concentration in the cement interface which leads to abutment tooth movement[(15)]. To eliminate this problem, PEEK surface energy is increased using traditional sanding, roughening with acid, plasma spray and laser roughening methods.[(16)]

Bonding protocol was strictly followed to all samples according to the manufacturer recommendations. Total etch bonding technique was chosen as it is the gold standard technique to ensure optimum bonding. It is important to note that bond strengths of untreated specimens were not tested, because studies have shown that it was not possible to obtain adequate bondstrength between PEEK and resin cement with an untreated surface.

One-step dentin bonding systems exhibit lower bond strengths than multi-step etch-and-rinse and self-etch systems; additionally, the one-step dentin bonding systems are less predictable[(17)]

Resistance form is the feature of a tooth preparation that increases the stability of arestoration and resists dislodgement along an axis other than the path of placement. Adequate resistance to dislodgement depends on three factors:

(a) Magnitude and direction of the dislodging forces.
(b) Geometry of tooth preparation(18).
(c) Physical properties of luting cements.

Of these three factors, the magnitude and direction of the dislodging forces are an inherent patient factor that the dentist may not be able to control adequately.

Proussaefs *et al*.(19)explained the effectiveness of mesiodistal grooves, mesiodistal boxes, and TOC in enhancing resistance form. They concluded that grooves and boxes did not increase the resistance form significantly.

Roudsari and Satterthwaite(20) suggested interproximal grooves and reduction in TOC to enhance resistance form. However, they found that reduction in cervical TOC was more effective than interproximal grooves.

Farshad *et al*.(21) recommended mesioocclusal distal isthmus, occlusal inclined plane, and reduced TOC to enhance resistance form.

Tiu *et al*.(22) recommended that TOC values have increased over the past four decades from an unachievable 2°–5° taper to a more realistic 10°–22

3M™ ESPE™ RelyX™ Unicem Self-Adhesive Universal Resin Cement is a dual-cure, self- adhesive universal resin cement in a capsule, designed for adhesive luting of all-ceramic, metal or composite indirect restorations, including fiber posts. RelyX Unicem self-adhesive universal resin cement has been developed for universal luting of both ceramic and metal-based restorations.

Alongside various luting cements, bonding primer has also provided improvement of PEEK bonding behaviour. A satisfactory bonding strength can be achieved by Visiolink because of its specific composition of pentaerythritol triacrylate (PETIA) in solution, MMA monomers, and additional dimethacrylates, which causes micro-interlocking between resin cement and PEEK and increases the SBS of PEEK. Caglar et al. found that PEEK conditioning with Visiolink provided higher SBS in comparison to PEEK with no adhesive treatment (12.54 ± 2.19 MPa vs. 5.58 ± 0.38 MPa); the adhesive performance was further optimized by combination of Visiolink and sandblasting (SBS, 19.86 ± 2.52 MPa)(23)

There has been a trend towards fewer and simpler clinical application steps of resin cementation for reliable fixation in dentistry(24,25). The resin cements are now required to be biocompatible to the enamel and dentin, adhesive to the various prosthodontic restorative materials, sufficiently functional to sustain the hydro-, hydrothermal, mechanical stresses and resistant to failure. Self-etch adhesives help achieve the high early resin-dentin bond strength values, but their resistance to thermal and mechanical stresses over time is diminishing(26). It is important to have an understanding of the interplay and mutual effects of the different stresses on the mechanical properties of bonding materials(27). Knowledge regarding the stress distribution at the bonded interface, the effects of materials, and loading method used are essential to explain the results.

The oral hard tissues and their environment are complex. Not surprisingly, the mechanisms of adhesion that have been successfully employed are also complex. In general, the following factors can play major or minor roles in achieving adhesive bonds:

1. Wetting
2. Interpenetration (formation of a hybrid zone)
3. Micromechanical interlocking
4. Chemical bonding

Wetting is essential for the success of all other adhesion mechanisms. An adhesive cannot form micromechanical interlocks, chemical bonds, or interpenetrating networks with a surface unless it can intimately contact the surface, spread onto the surface, and fill microscopic and sub microscopic irregularities. These conditions are achieved ifthe adhesive wetsthe surface. Although wetting is an essential requirement for intraoral adhesion, it is not sufficient to ensure durable bonding. 'This insufficiency is very unusual in the field of adhesives. For example, one can readily form strong, durable bonds between sheets of plate glass by using an epoxy resin. This cornbination involves no primary chemical bonding between adhesive and adherent, no micromechanical interlocking, and no interpenetration. However, one cannot expect the same result when tooth structure is the substrate. Wetting or tooth structure alone does not achieve lasting intraoral bonds because the principal substrates (adherents), enamel and dentin, are hydrated, hydrophilic, and permeable to water. Such adherents require a hydrophilic, hydrolytically stable adhesive for wetting to occur. However, even if the surface is initially dried before adhesive application, diffusion results in one or more monolayer of water that strongly bond to both the tissue and the adhesive. Unfortunately, water has a very low shear strength, so the net shear bond strength between two perfectly flat surfaces is insignificant (28).

The mean of SC is 146.37 and of SCG is 95.57 which is because the bonding of self adhesive resin cement which is RelyX is more with enamel than dentin.While preparing short crown Containing grooves we make grooves of 0.3 mm which is extended into the dentin and thus the bonding of tooth with cement is decreased.

Short endocrowns (mean 109.72) contain enamel in 360 which therefore has more bonding to cement than SCG.

According to Rosenstiel Crown containing grooves or boxes show more retention than crown without grooves, but in case of short crowns, less Total occlusal convergence provides more retention than grooves or boxes. Therefore the tensile bond strength of SC is more than SCG.

Scope for further research and limitations:

1) In the present study tensile bond strength between 3 groups were compared. Shear bond strength between the same groups can also be compared in future.
2) In present study only one cement is used between three groups. Test can be carried out using other cements as well.
3) This is in-vitro study. Similar kind of study can be carried out under oral conditions. Then, the bond strength carried between 3 groups can be evaluated.

V. Conclusion

Based on the findings of current study following conclusions can be drawn:

1. Tensile Bond Strength of Short Clinical crown Without Grooves (146.37) is more than Short Clinical crown with grooves (95.57). The reason is that the bonding of resin cement (RelyX Unicem) is better with Enamel than Dentin.
2. Tensile Bond Strength of Endocrown is less than Short clinical crown without grooves but more than that of Short Clinical crown With Grooves,even though we have entered into the dentin while preparing endocrown is because of the presence of complete enamel layer (360) around the endocrown. This present complete enamel layer shows more bonding of RelyX cement to enamel than dentin.
3. According to present literature incorporation of grooves and boxes while preparing tooth helps in increasing the retention and resistance form but when it comes to short clinical crowns grooves and boxes does not help in aiding the retention. Rather decrease in Total Occlusal Convergence helps in increasing retention.

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