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In-Vitro evaluation of fracture strength of zirconia and peek anterior FPD Framework

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***Abstract*---**Zirconia's fracture strength is well known, so that this work was aimed at evaluating PEEK's fracture strength and comparing it with Zirconia. The primary objective of this study was to compare the fracture strength in computer-based design, production with computer assistance, 3-unit Zirconia anterior and PEEK frameworks. Prefabricated 3-unit anterior FPD dental models were produced and scanned in relation to 21,22 and 23 using a 3-shape, Trios intraoral scanner, metallic die-milling employing base metal alloy. The same oral Intra scanner has been utilised for metallic die scanning (3 shape, Trios). Five CAD/CAM Zirconia 3-unit frameworks were created and metallic die cement was employed for concrete purposes, including five PEEK 3-unit (B group), for bonding resin cement was used. The strength of the fracture was tested by a universal test equipment. The force was applied to the specimen with a crosshead speed of 0.5 mm/min on the Pontic tooth 22 until the catastrophic collapse took place. The average strength fracture value for each FPD was recorded and analyzed statistically by unpaired student T-test. The

average CAD/CAM Zirconia fracture strength was 1872 N ± 12.55 N and the average CAD/CAM PEEK fracture strength was 2573 N ±13.33 N. The CAD/CAM PEEK fracture strength was higher than CAD/CAM Zirconia. Statistically, the values were significant by 1% (p value < 0.01). PEEK could be an alternative metal free, cosmetic material for replacing missing teeth since the value of the fractures were considerably higher compared to Zirconia.

***Keywords*---**denture, partial, fixed, zirconium, PEEK, flexural strength

Introduction

In clinical dentistry a lost tooth is a typical occurrence due to several factors. Replacing a missing tooth is challenging especially in the anterior region due to the soft and hard tissue makeup, aesthetics, phonetics, functional and occlusal requirements. Resin-bonded Fixed Partial Dentures, Conventional Fixed Partial Dentures (FPDs), Removable Partial Dentures and Implant-supported Fixed Prosthesis are the prosthetic alternatives for replacing missing anterior teeth. New materials have been developed to meet the requirement for aesthetics in fixed prosthodontics. Metal ceramic and all ceramic are the most popular permanent materials utilized for anterior tooth replacement. Because of metal show through, metal-ceramics create "graying" of the gingival margin and have the potential to trigger allergic or toxic reactions in the soft or hard tissues.[1] Because of the use of these materials, metal-free options such as all-ceramic restoration and, more recently, PEEK to replace missing anterior teeth have been developed.

When used for FPDs, all ceramic crowns such as the IPS Empress and E-max give good esthetics but lacks the strength. Since the 1960s, Zirconia crowns have been utilized because of its great strength and reliability, Yttria-stabilized Tetragonal Zirconia Polycrystal (3Y-TZP) is widely in use. Monolithic or bi-layered ceramic crowns are available, Alumina, Zirconia, Zirconia toughened Alumina, Magnesium Aluminate, and Lithium Di-Silicates are used in the core of bi-layered restorations to replace teeth in the aesthetic region. To create the final aesthetic repair, veneering porcelain is put to the core once it has been manufactured. Fracture of the veneering ceramic from its core is the most prevalent failure of these bilayered crowns and bridges.[2] All-ceramic FPD failures were formerly attributed to a lack of adherence to the underlying tooth substance before the introduction of silanation. Silanation allowed for a chemical bond to be formed between the etched porcelain and the tooth. Alternative ceramics like monolithic lithium disilicate, which have a lower fracture strength than monolithic Zirconia, are used in monolithic crowns. Mono-block restorations made of pure Zirconia (full contour Zirconia crowns) have the potential to improve mechanical stability, broaden the spectrum of indications, and improve dependability and load endurance.[3] Despite good staining, they are nevertheless inferior to their lithium disilicate counterparts in terms of aesthetics. As a result, their indications are confined to posterior single crowns and FDPs with a small span.

PEEK is a feasible alternative to Zirconia full contour crowns, which can not only withstand occlusal stress but also provide good esthetics when used in the anterior. PEEK is a sulfonated aromatic high-temperature thermoplastic polymer with

extremely high mechanical strength. It is very inert, chemically resistant, has bone-like elasticity, and can sustain high temperatures. It also has a low plaque affinity and is non-allergic. PEEK is a commonly used biomaterial that works well as a bone substitute.[4] Apart from physiological advantages, its aesthetic qualities such as color resemblance to real teeth, radiolucency, rigidity, and light weight, make it an ideal material for dental restorations.

PEEK is widely utilized in the CAD/CAM fabrication of dental implants, provisional abutments, implant-supported bars, detachable prosthetic framework, and fixed dental prostheses.[5] The PEEK structure is coated with microfilled veneering composite resin in fixed partial dentures. First, an opaque paste of the desired shade is applied to the framework and light cured for 10 minutes, then layers of deep dentin shade, dentin body, and incisal shades are applied, with periodic curing between each application. [6]

There are few studies that evaluate the mechanical properties of PEEK in the literature. There have only been a few investigations on the fracture strength of PEEK to date. They compared Zirconia and PEEK material in the posterior tooth region in an in-vitro study titled "Fracture strength of three-unit implant supported fixed partial denture with excessive crown height manufactured from different materials." There is no scientific evidence that the anterior FPD framework consisting of Zirconia and PEEK has a high fracture strength.[7]
This study was done to compare the fracture strength of a three-unit CAD/CAM FPD frame made of Zirconia and PEEK attached to a metal die cemented via resin. The present null hypothesis in vitro is that between the CAD / CAM anterior FPD Zirconia-PEEK frameworks there is no significant variation in the fracture strength.

Materials and Methods
Fabrication of prepared tooth model

A Prefabricated three-unit anterior FPD gypsum model (Bredent, Germany) with missing 22 and prepared 21,23 was obtained . The model was digitally designed with a 6-degree taper in relation to 21 and 23.

Fabrication of metallic die

The model was scanned with a Trios 3 Shape intraoral scanner, and the Standard Tessellation Language file was then exported to the graft 3D Healthcare solution for metallic die production. The metallic die was digitally constructed to imitate the mouth state, with the teeth at a 30-degree angle to the floor, such that the specified load is subjected to lingual fossa of 22. If not, the force will be applied to the crown's incisal edges. Cobalt chromium base metal alloy was used to 3D print the metallic die. For improved bonding and to avoid adhesive failure, the exterior surface of the metallic die was sandblasted with Al_2O_3.

Fabrication of CAD/CAM zirconia and peek framework

Intra oral scanner was used to scan the metallic die (3 Shape, TRIOS). A total of five 3-unit CAD/CAM PEEK and Zirconia frameworks were created. Exocad Dental DB 2.2 Valletta program was used to design the framework digitally. The connector between the central incisor and the lateral incisor measured 4.44mm in height, 3.08mm in width, and 11.01mm in area, while the connector between the lateral incisor and the canine was 4.55mm in height, 3.04mm in width, and 11.12 mm in area. Dual cure resin cement was used to adhere the structure to the metallic die. To test the fracture strength of the metallic die and the framework, they were loaded.

Fracture strength evaluation

The fracture strength was assessed using a universal testing equipment (Servo Controlled, Model - F 100). With a 5mm diameter spherical head installed in a computer-controlled universal testing equipment and a crosshead speed of 0.5 mm/min, all samples were subjected to compressive axial loading. The load was applied to the lingual fossa of Pontic tooth , that is, tooth number 22 only until it failed catastrophically and no load was applied to 21 and 23 at any point of time as illustrated in Fig. 1(b) and Fig. 1(c). Catastrophic failure was defined as the presence of visible cracks, load decreases, and chipping or fracture acoustic events. This was done for all samples, and the results were recorded and analyzed statistically.

Statistical Analysis

From the data obtained the mean values for group A and Group B were calculated. Statistical analysis was done with Mann-Whitney U test to compare the mean value of fracture strength between the CAD/CAM Zirconia framework (Group A) & CAD/CAM PEEK framework (Group B). The Shapiro Wilk test was used to assess the distribution conformity of examined parameters with a normal distribution.

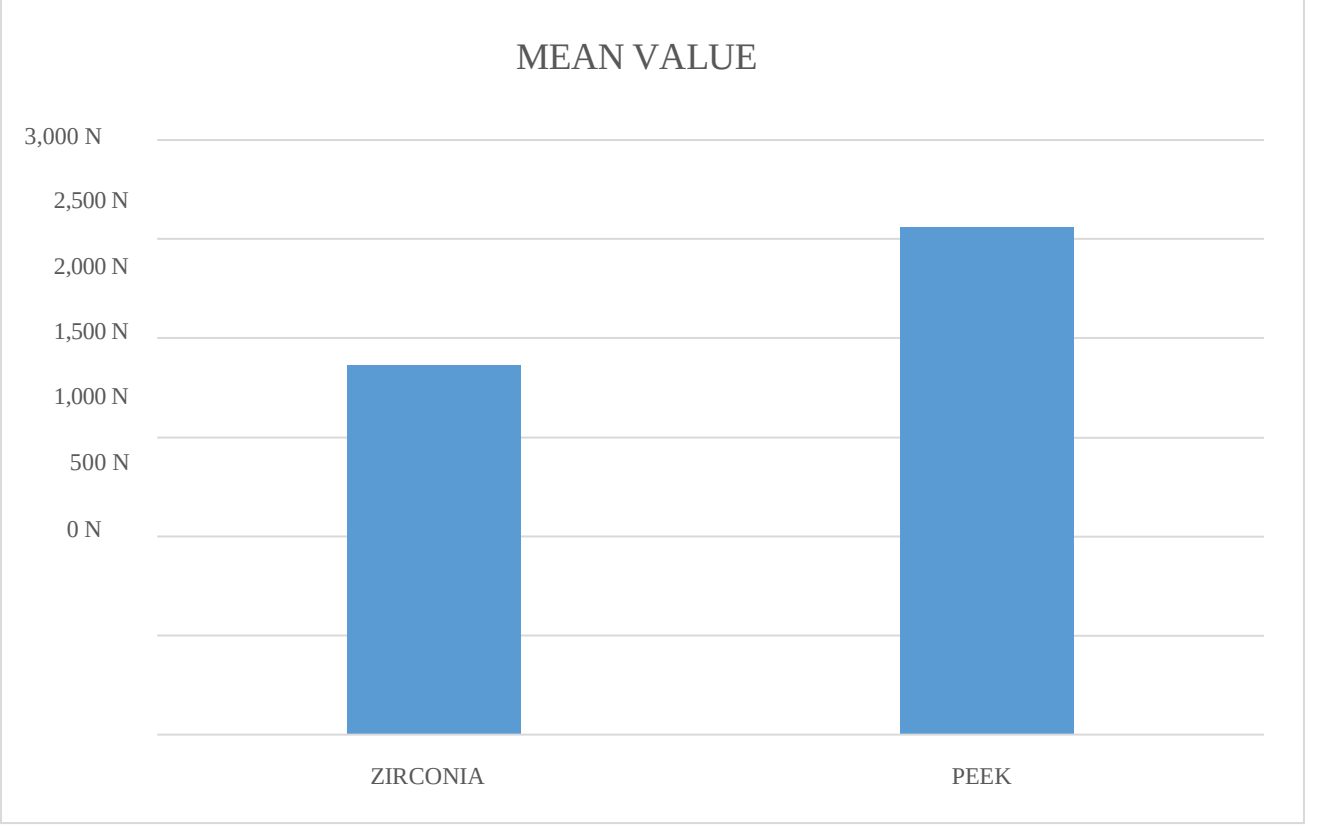
Result

The current in-vitro study evaluates the fracture strength of the anterior FPD framework of 3 units CAD/CAM produced with Zirconia and PEEK compared to the present. All the samples in Group A (Zirconia) and Group B (PEEK) were subjected to compressive axial loading with a 5mm diameter spherical head mounted in a computer-controlled universal testing machine at a crosshead speed of 0.5 mm/min and the force at which the material fracture were noted with the load displacement curve. Statistical analysis was done with Mann-Whitney U test to compare the mean value of fracture strength between the CAD/CAM Zirconia framework (Group A) & CAD/CAM PEEK framework (Group B). The values obtained for PEEK (Group B) was higher than the values obtained for Zirconia (Group A). The Shapiro-Wilk test was used to assess the distribution conformity of examined parameters with a normal distribution and the null-hypothesis of this test was that the values were normally distributed which was rejected as p value was found less than 0.01. The highest fracture strength value and for Zirconia & PEEK was 1894 N and 2650 N respectively where as mean was 1872±12.55 N and 2573 N ±13.33 N respectively as shown in Table 1, Graph 1.

Table 1: Statistical result

VARIABLES	ZIRCONIA			PEEK			t - Test	P - Value	RESULT
	N1	MEAN	±SD	N2	MEAN	±SD			
N	5	1872.00	12.55	5	2573.00	13.33	23.72	0.00	Statistically significant (p<0.01)

Graph 1: Mean values of fracture strength of zirconia and peek framework



Discussion

Fixed prosthodontics is a branch of prosthodontics which is involved in replacing or rehabilitating teeth with no artificial replacements from the mouth. A fixed partial denture (FPD) is a device which is securely attached to natural teeth/dental implant abutments that support the prothesis primarily.

In the previous three decades, rehabilitation of teeth with crowns has increased considerably. The finished FPD is made of all ceramic, fused metal porcelain or all-metal. All restorations may fail one or other way. Fixed partial dentures may fail biologically, aesthetically, mechanically or a combination of all. A variety of various

causes can result in the mechanical failure of restorations[8,9] and also can vary depending on the type of fracture occurring.

Despite significant progress in the development of newer and stronger metal-ceramic systems, the 'gold standard' in prosthodontics has been maintained since the 1960s when they were launched. Metal ceramic crowns, in particular the fracture of the furnace porcelain is prone to mechanical fracture. After 10 years of clinical services, Eliasson *et al.*[10] reported 97% survival in metal-ceramic restorations. A thorough examination carried out by Goodacre *et al* [11] found that the veneering of porcelain fracture is the most frequent complication of metal ceramic prostheses. The strength being the advantage over the aesthetics when compared to techniques, material properties and uses when compared the metal-ceramic crowns with all ceramics. Initially, the development of all ceramic crowns was not accepted well due to failures. All ceramic crowns were shown similar mechanical capabilities to that of metal ceramic crowns with the improvements of technology and materials at Zirconia core 2009 and 2012. [12,13]

Fracture strength of restorative materials is important to predict both the clinical service and failure rates. The strength of the fracture is defined as the capacity of a resistant material to defect and is precisely identified according to the loading method used, such as tensile, compressive or bending. The strength of the fracture is sometimes called the force applied until breakage. A specimen fails due to a fracture, because of the stress. The last point is the strength of the fracture.

The purpose of this study was to analyse comparably the fracture strength of the Zirconia & PEEK CAD/CAM frame of the same thickness. The null hypothesis of the study was that the strength of CAD/CAM 3-unit FPD framework built out of Zirconia (Group A) and PEEK fractures was not significantly affected. (Group B). To avoid operator-based errors, all the procedure mentioned in methodology was performed by single operator.

For a therapeutically important in vitro load to failure test protocol for all ceramic restorations, Kelly provided several parameters which were followed in our study.[14] This includes the preparation of teeth and the cementation of the crowns by trustworthy and most often used luting cement. The dentures have been digitally developed for all ceramic anterior teeth with a 6° taper in accordance with clinical recommendations. If the tooth preparation is done in a mistake, no precise taper model and perfect size reduction can be made manually. The metallic die was then digitally developed for standardisation and the Zirconia and PEEK framework were then designed. The crowns were glued by dual-cure resin cement which is the most frequent combing cement to cement all ceramic crowns.

CAD/CAM Zirconia's average fracture strength is 1872 N ±12.55 N and CAD/average PEEK's fracture strength is 2573 N ±13.33 N [14]. The CAD/CAM PEEK Framework fracture strength was substantially greater than the CAD/CAM Zirconia. Hence the results support the rejection of the null hypothesis because significant differences were observed.

The maximum strength in the molar area is usually higher. In healthy and naturally occurring humans, a unilateral measurement in molar areas has an average bite force

between 216 and 890 newtons. With the transducer positioned on the anterior teeth, the unilateral force recorded in the molar region is around 40% [15], and it is approximately 70% with the transducer in the Premolar region. In the molar area maximum occlusal forces have been observed up to 909 N [16,17,18,19,20]. For the anterior teeth therefore, the maximal mean strength is about 500 N. The protheses need to handle this load at least double. This is because the restorations in the oral cavity are undergoing a reduction of force over time of about 50% of the initial value, so that when they are placed in the mouth, the initial strength value must be roughly double the average of the principal forces developing in these locations. The thrust of 1000 N is thus very significant and the FPD framework of Zirconia and PEEK exceeds this threshold that has been extensively confirmed. Hence both Zirconia and PEEK can be used as a framework material in anterior Fixed Partial Denture.

In a study conducted by Zahran *et al.*[20] the result indicated that Zirconia crowns had mean fracture loads of 1459 N. The mean Zirconia group fracture load was 2077 N in a study by Manoharan *et al.*[21] In a study by Wael Att *et al.*[22] the mean fracture strength of Zirconia ranged from 1522 N to 1702 N. An in vitro study by Dornhofer *et al.*[23] showed a mean fracture strength of 2527 N. A Study by Stiesch-Scholz *et al.* [24] showed a mean fracture strength of 1265 N. Study by Tinschert *et al.*[25] the mean fracture value of Zirconia was greater than 2000 N and a study by Rountree *et al.*[26] showed a mean fracture strength of 1816 N.

From the above-mentioned in vitro studies, the mean fracture load of Y-TZP based all-ceramic FPDs is reported to be in the range of 1200 N to 2600 N. The fracture strength of Zirconia framework obtained in this study also ranges within these values. Different values are obtained in different studies. The rationale is similar, although in other investigations, techniques have been implemented in certain studies with regard to artificial ageing (thermal and mechanical cycles). The artificial ageing processes are designed to imitate a patient's mouth that is constantly under mechanical stress and temperature variations.

The ceramic-ceramic frameworks cracked with the entire ceramic curve thickness. For all ceramic material this is the predicted mechanism of fracture. Unlike Zirconia, PEEK framework did not fracture completely instead formation of a visible crack at the connector region was noted which could be due to the high flexural strength of the material. Regarding comparison between Zirconia and PEEK, there are two studies regarding the fracture strength of 3-unit FPD made of PEEK. Both the studies have investigated the fracture strength in posterior region. Vahideh Nazari *et al.*[7] in 2016 compared the fracture strength of bilayered Zirconia and PEEK framework veneered with composite. He concluded that at a given load the fracture that occurred in zirconia involved both framework and veneering material whereas in PEEK only the veneering material fractured and the framework remained intact which supports this study. Connector is the fixed portion of the retainer which links the pontic. The connector is the weak spot for full restorations and the height and width of the connector should be modified to allow the restoration to continue for a long time. Indeed, it was found in a number of investigations that a breakdown in the gingiva part of the connection nearly invariably results in a failure of the restauration.

Study of Studart *et al.* [27] Based on the assessment of some prothesis fatigue metrics, the connector dimensions should be 5.7 mm^2, 12.6 mm^2 and 18.8 mm^2 for bridges of

3, 4 and 5 units, respectively. For a minimum connection size of 6 to 9 mm^2, the connection is to be 6 mm^2 for the three units.

Conclusion

Based on the results obtained in the present in-vitro investigation, it may be concluded that PEEK is a reliable material to be used as framework for Fixed Partial Denture. Zirconia and PEEK both can be used for replacing anterior owing to comparable strength. The findings in the current study also suggest PEEK to be interesting alternative for use as core material for restoration of anterior tooth region. Clinical studies with long term follow-up are however, necessary to assess the clinical performance.

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Figure

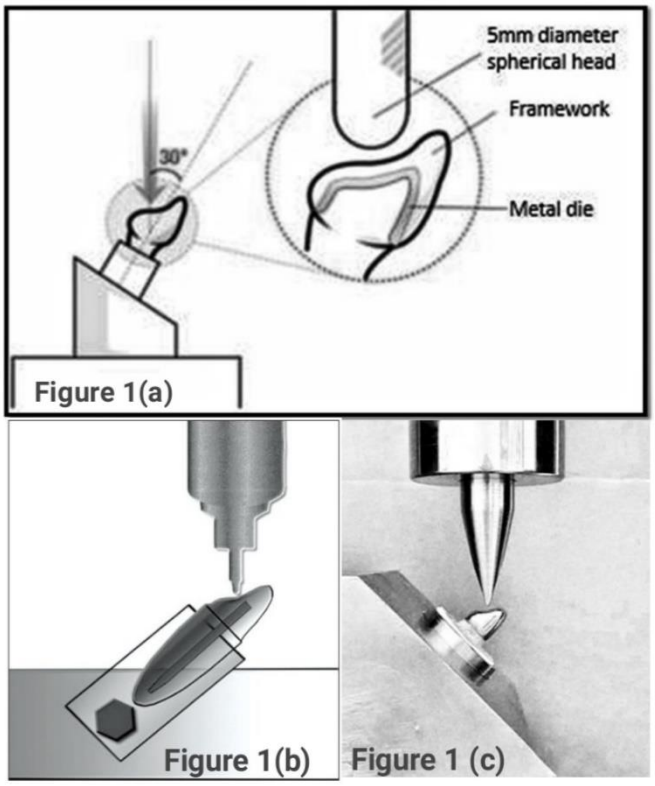

Figure 1 (a): Schematic diagram showing 30-degree tilt of Metal die
Figure 1(b)&(C): Load on the Lingual Fossa of Pontic tooth 22