Avances en Biomedicina
Publicación Oficial del Instituto de Inmunología Clínica
Mérida-Venezuela
Volumen 14(2), Julio-Diciembre 2025, p 140-148

Depósito Legal: PPI201102ME3935
ISSN: 2477-9369
PII: S2477-9369(25)14018-O

Comparative evaluation of fracture strength of CAD/CAM anterior FPD framework made with zirconia and peek–an in-vitro study

(Evaluación comparativa de la resistencia a la fractura de una estructura de FPD frontal flexible anterior CAD/CAM fabricada con zirconia y peek: un estudio in vitro)

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Received: 17th March 2025
Accepted: 12th August 2025.
Online publication: 3rd October 2025.

[ARTÍCULO ORIGINAL]

PII: S2477-9369(25)14018-O

Abstract(english)

This study aimed to comparatively evaluate the fracture strength of Computer Aided Designing, Computer Aided Manufacturing, 3-unit anterior Zirconia, and PEEK framework. A prefabricated prepared teeth model for 3-unit anterior FPD in relation to 21,22 & 23 was obtained and scanned using 3 Shape, Trios intraoral scanner, and a metallic die was milled using base metal alloy. The metallic die was scanned using the same Intraoral scanner (3 shape, Trios), and five 3-unit CAD/CAM Zirconia (Group A) and five 3-unit PEEK (Group B) frameworks were fabricated and cemented to the metallic die using resin cement. A universal testing machine was used for the fracture strength evaluation. The load was applied to the specimen at a crosshead speed of 0.5mm/min until catastrophic failure occurred. This was repeated for all the FPD frameworks, and the fracture strength mean value was recorded and statistically analyzed through an Unpaired Student t-test. The mean fracture strength of CAD/CAM Zirconia is 1862 N +18.8149 N, and the mean fracture strength of CAD/CAM PEEK is 2563 N +19.7231 N. The Fracture strength of CAD/CAM PEEK framework was higher than that of CAD/CAM Zirconia framework. The values were statistically significant by 1% (p value < 0.01). Since PEEK showed a significantly higher fracture strength value compared to Zirconia, it could be an alternative metal-free, esthetic material for replacing missing anterior teeth.

Keywords(english)

Fixed partial denture, Fracture strength, Polyetheretherketone, Zirconia.

Resumen(español)

Este estudio tuvo como objetivo evaluar comparativamente la resistencia a la fractura del diseño asistido por computadora, la fabricación asistida por computadora, la zirconia anterior de 3 unidades y el marco de PEEK. Se obtuvo un modelo de diente

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preparado prefabricado para FPD anterior de 3 unidades en relación con 21, 22 y 23 y se escaneó utilizando 3 Shape, escáner intraoral Trios, y se fresó un troquel metálico utilizando una aleación de metal base. El troquel metálico se escaneó utilizando el mismo escáner intraoral (3 shape, Trios), y se fabricaron cinco estructuras de zirconia CAD/CAM de 3 unidades (Grupo A) y cinco estructuras de PEEK de 3 unidades (Grupo B) y se cementaron al troquel metálico utilizando cemento de resina. Se utilizó una máquina de prueba universal para la evaluación de la resistencia a la fractura. La carga se aplicó a la muestra a una velocidad de cruceta de 0,5 mm/min hasta que se produjo una falla catastrófica. Esto se repitió para todas las estructuras de FPD, y el valor medio de la resistencia a la fractura se registró y se analizó estadísticamente mediante una prueba t de Student no pareada. La resistencia media a la fractura del zirconio CAD/CAM es de 1862 N + 18,8149 N, y la del PEEK CAD/CAM es de 2563 N + 19,7231 N. La resistencia a la fractura de la estructura de PEEK CAD/CAM fue superior a la de la estructura de zirconio CAD/CAM. Los valores fueron estadísticamente significativos al 1 % ($p < 0,01$). Dado que el PEEK mostró una resistencia a la fractura significativamente superior a la del zirconio, podría ser un material alternativo, sin metal y estético, para la sustitución de dientes anteriores faltantes.

Palabras clave(español)

Prótesis parcial fija, Resistencia a la fractura, Polieteretercetona, Zirconia.

Clinical significance

Introduction of Zirconia in dentistry has expanded the possible application of metal-free ceramic restoration with great success and reliability. Among the clinical complications of Zirconia FPD's, crown/connector fractures are reported most commonly. As PEEK (Polyetheretherketone) is high performance polymer, with low modulus of elasticity, resulting in shock shock-absorbing effect, which makes it less prone to fracture. Fracture strength of Zirconia is well known; hence this study aimed to evaluate the fracture strength of PEEK and compare it with Zirconia

Introduction

A missing tooth is a common condition in clinical dentistry. The replacement of missing tooth in the anterior region is challenging because of the soft and hard tissue, esthetic, phonetic, functional, and occlusal requirements. The prosthetic options for replacement of missing anterior teeth are Resin-bonded Fixed Partial Dentures, Conventional Fixed Partial Dentures (FPDs), Removable Partial Dentures, and Implant-supported Fixed Prosthesis. The demand for esthetics in fixed prosthodontics has led to development of new materials. The permanent materials most commonly used for restoration of anterior teeth are Metal ceramic and All ceramic. Metal-ceramics cause "graying" of the gingival margin because of metal show through and have the potential to cause allergic or toxic reactions within the soft or hard tissues (1). Use of these materials, have resulted in the development of metal free alternatives that is All ceramic restoration and more recently PEEK to restore the missing anterior teeth.

All ceramic crown like IPS Empress & e-max provide good esthetics but lack strength when used for FPD's. Zirconia crowns has been used since 1960's. Yttria-stabilized Tetragonal Zirconia Polycrystal (3Y-TZP) has been used for its high strength and good reliability. All ceramic crowns can be Monolithic or Bilayered. Bilayered restorations are used to replace teeth in esthetic region where the core is fabricated using Alumina, Zirconia, Zirconia toughened Alumina, Magnesium Aluminate Spinel and Lithium silicate. Once the core is fabricated, veneering porcelain are applied to the core to create the final esthetic restoration. The most common failure of these bilayered crowns and bridges are fracture of the veneering ceramic from its core (2). Before the advent of silanation, all-ceramic FPD failures were also attributed to a lack of adhesion to the underlying tooth substance. Silanation provided a means by which a chemical bond between etched porcelain and the tooth could be achieved. Monolithic crowns are made up of alternative ceramics like monolithic lithium disilicate which showed lower fracture strength than those made of monolithic Zirconia. Fabricating mono-block restorations from pure Zirconia (full contour Zirconia crowns) could increase the mechanical stability, expand the range of indications and also provide a higher reliability and sustain loading (3). But from the esthetic point of view, they are still inferior to their lithium disilicate in spite of adequate staining. Therefore, their indication range is limited to posterior single crowns and short span FDP's.

PEEK is a viable alternative to Zirconia full contour crowns, which could not only be able to resist occlusal loading but also provide good esthetics when used for an anterior esthetics. Polyetheretherketone (PEEK) is a sulfonated aromatic high-temperature thermoplastic material with very high mechanical strength. It is highly inert, resistant to chemical erosion, exhibits bone like flexibility and withstands high temperature. It is also non-allergic and has low plaque affinity. PEEK is widely accepted as a biomaterial and is an excellent substitute of bone (4). Apart from physiological properties, its esthetic properties such as proximity to natural teeth color, radiolucency, rigidness and light weight makes it the perfect choice for dental restorations.

PEEK is used widely in CAD/CAM manufacturing for dental implants, provisional abutments, implant-supported bars, framework for removable prostheses, and fixed dental prosthesis (5). When used in Fixed partial denture the PEEK framework is layered with microfilled veneering composite resin. At first the opaque paste of selected shade is applied on the framework and then light cured for 10 minutes, followed by layering with deep dentin shade and subsequently with dentin body and incisal shades with periodic curing after each application (6).

Studies evaluating the mechanical properties of PEEK are limited in literature. Till date there only few studies regarding the fracture strength of PEEK. An in-vitro study on "Fracture strength of three-unit implant supported fixed partial denture with excessive crown height fabricated from different materials" where they compared Zirconia and PEEK material in posterior tooth region (7). There is no scientific information available regarding the fracture strength of anterior FPD framework made with Zirconia and PEEK.

This study aimed to comparatively evaluate the fracture strength of three-unit anterior CAD/CAM FPD framework made with Zirconia and PEEK cemented to metal die with resin cement. The Null hypothesis of the present in-vitro study is that there would be no significant difference in fracture strength of CAD/CAM anterior FPD framework made with Zirconia and PEEK.

Materials and methods

Fabrication of metallic die. A prepared three unit anterior FPD gypsum model was obtained (Figure 1a). The model was scanned using Trios 3 Shape, intraoral scanner and the STL file was exported to graft 3D Healthcare solution, for metallic die fabrication. To simulate the oral condition, the metallic die was digitally designed such that the teeth are in 30-degree angulation to that of the floor, so that the given load is subjected to cingulum (Figure 1b and c). If not the force given will be subjected to the incisal edges of crown. Metallic die was 3D printed with cobalt chromium base metal alloy. The outer surface of the metallic die was sandblasted with Al_2O_3 for better bonding and to avoid the adhesive failure.

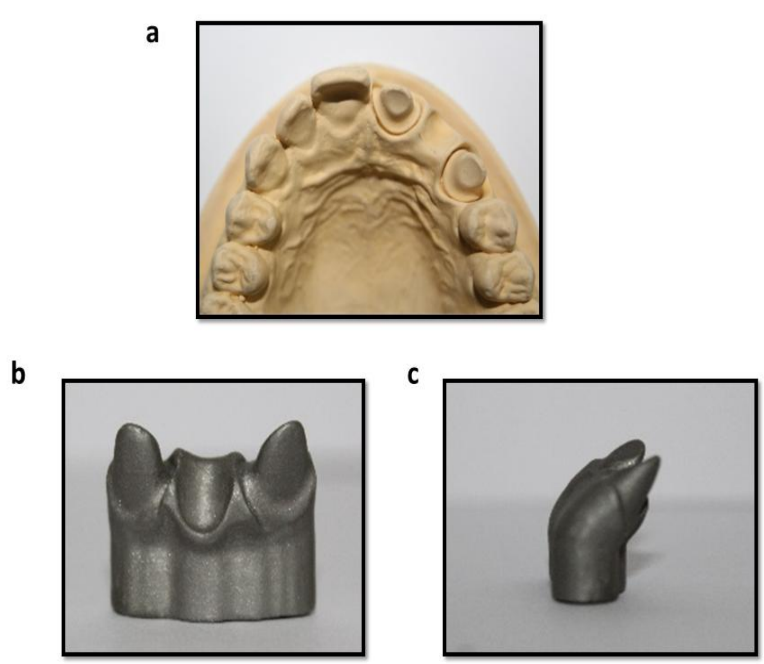

Figure 1. 1a. Prepared tooth model. **1b and 1c.** Mettalic die.

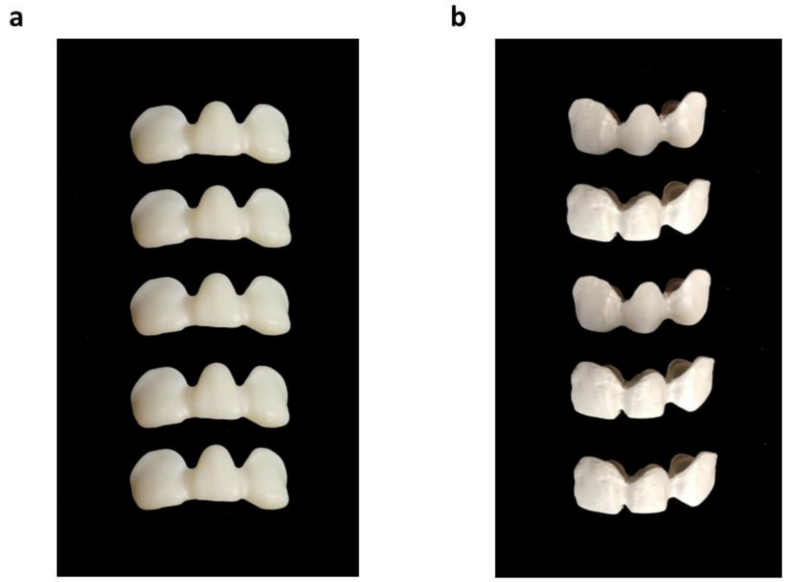

Figure 2. 2a. CAD/CAM three-unit zirconia framework. **2b** CAD/CAM three-unit peek framework.

Fabrication of cad/cam zirconia and peek framework. The metallic die was scanned using Intra oral scanner (3 Shape, TRIOS). Total of 5 CAD CAM 3-unit and Zirconia (Figure 2a) and PEEK (Figure 2b) framework was fabricated. The framework was digitally designed using Exocad Dental DB 2.2 Valletta software. The connector between the central incisor and lateral incisor had a height of 4.96 mm, width of 3.12, and an area of 11.09mm and the connector between the lateral incisor and canine had a height of 4.93mm, width of 3.18 mm and an area of 11.52 mm. The framework was cemented to the metallic die using dual cure resin cement. The metallic die along with the framework was subjected to load to evaluate the fracture strength.

Fracture strength evaluation. Universal testing machine (Servo Controlled, Model - F 100) was used for the fracture strength evaluation. All samples were subjected . 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. The load was applied to the lingual fossa of the framework until catastrophic failure occurred (Figure 3). Catastrophic failure was defined as the exhibition of visible cracks, load drops, and acoustic events of chipping or fracture. This was repeated for all samples and the values were recorded and statistically analyzed (Figure 4a and b).

Results

The present in-vitro study was conducted to comparatively evaluate the fracture strength of three-unit CAD/CAM anterior FPD framework made with Zirconia and PEEK. All the samples in Group A (Zirconia) and Group B (PEEK) were subjected to compressive axial loading with a 5mm diameter spherical head mounted

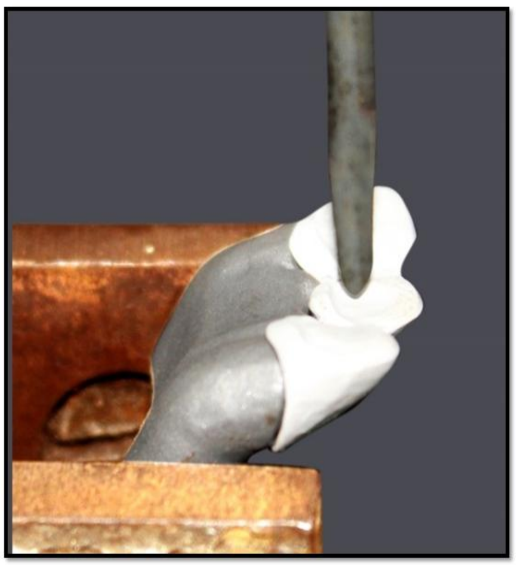

Figure 3. Fracture strength evaluation.

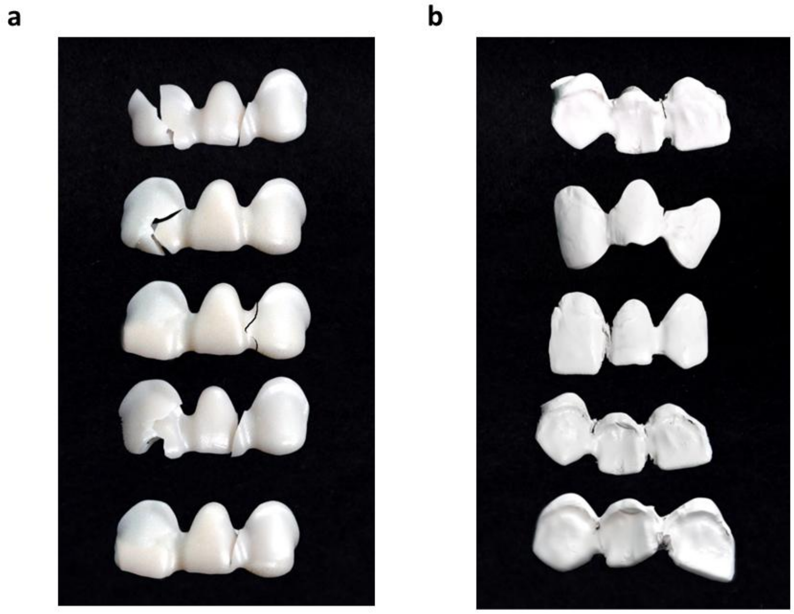

Figure 4. 4a. Fractured CAD/CAM three unit zirconia framework. **4b.** Fractured CAD/AM three unit peek framework.

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. The values were tabulated as following.(Table 1)

Inference. Statistical analysis was done with Non parametric Unpaired Student t-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). It is statistically significant by 1%. (p value <0.01).

• The highest fracture strength value for Zirconia was 1890 N.

• The highest fracture strength value for PEEK was 2610 N.

• The mean fracture strength value for Zirconia was 1862 N +18.8149 N.

• The mean fracture strength value for PEEK was 2563 N +19.7231 N.

Table. 1. Fracture strength of zirconia and peek framework.

S.no	Zirconia (group a)	Peek (group b)
1	1890 N	2500 N
2	1790 N	2600 N
3	1880 N	2550 N
4	1890 N	2610 N
5	1860 N	2555 N

Discusion

Fixed Prosthodontics is a branch of Prosthodontics concerned with the replacement or restoration of teeth with artificial substitutes that are not removed from the mouth. A Fixed Partial Denture (FPD) is a restoration that is luted or otherwise securely retained to natural teeth/tooth roots/dental implant abutments that furnish the primary support for the prosthesis.

Rehabilitation of teeth with crowns has increased greatly over the last three decades. The final crown or FPD is fabricated from All-ceramic, Porcelain Fused Metal, or All-Metal. All restorations are liable to failure during function. Failure of the fixed partial denture could be biologic, aesthetic, mechanical or a combination. Restoration failures are often a multi-factorial phenomenon. A number of different factors may be responsible for the mechanical failure of restorations (8,9) and factors may also vary depending on the type of fracture that has occurred.

Despite rapid advancements in the development of newer and stronger ceramic systems metal-ceramic restorations still remain the 'gold standard' in prosthodontics since their introduction in the 1960s. Metal-ceramics crowns are prone to mechanical fracture, especially fracture of veneering porcelain. Eliasson et al (10) reported a survival rate of 97% for metal-ceramic restorations after a period of ten years in clinical service. A systematic review by Goodacre et al (11) revealed that the fracture of veneering porcelain is the most common complication associated with metal-ceramic prostheses. Metal-ceramic crowns had advantages of strength and disadvantage of esthetics which was over comed with the evolution of materials and techniques. Evolution of all ceramic crowns was initially not well accepted due to failure rates. With technological and material advances in Zirconia core, all ceramic crowns were demonstrated comparable mechanical properties to that of metal ceramic crowns in 2012 (12) and 2009 (13).

Fracture strength of restorative materials is important to predict both the clinical service and failure rates. Fracture strength is defined as the ability of a material to resist failure and is designated specifically according to the mode of applied load, such as tensile, compressive, or bending. Fracture strength is also known as the breaking strength. It is the stress at which a specimen fails via fracture. The final recorded point is the fracture strength.

The aim of the present study was to comparatively evaluate the fracture strength of CAD/CAM framework made of Zirconia & PEEK of same thickness. The null hypothesis of the present study was that there would be no significant difference in fracture strength of CAD/CAM three unit FPD framework made of Zirconia (Group A) and PEEK (Group B).

To avoid operator-based errors, all the procedure mentioned in methodology was performed by single operator.

Kelly recommended few guidelines for a clinically relevant in vitro load to-failure test protocol for all-ceramic restorations which was followed in this study (14). This includes designing the prepared teeth and cementing the crowns with reliable and most commonly used luting cement. The teeth preparation was digitally designed according to clinical guidelines for all ceramic anterior teeth with 6°taper. If tooth preparation was done in a typodont model manually exact taper and accurate dimension reduction cannot be achieved. Following this, the metallic die and the Zirconia and PEEK framework was also digitally designed for standardization. The crowns were cemented using dual cure resin cement which is the most common luting cement used for the cementation of the all ceramic crowns.

The mean fracture strength of CAD/CAM Zirconia is 1862 N +18.8149 N and the

mean fracture strength of CAD/CAM PEEK is2563 N +19.7231 N. Fracture strength of

CAD/CAM PEEK framework was significantly higher than that of CAD/CAM Zirconia

framework. Hence the results support the rejection of the null hypothesis because significant differences were observed.

Maximum bite force is usually highest in the molar region. Unilateral measurement of maximum bite force in the molar region averages between 216 and 890 Newton in healthy adults with natural teeth. With the transducer placed on the anterior teeth the measured force is about 40% of the unilateral force recorded in the molar region (15), and with the transducer in the premolar region it is about 70%. Maximum occlusal forces up to 909 N (16-20) have been recorded in the molar region. Thus, the maximum mean forces for anterior teeth are around 500 N. It is necessary that the prostheses should bear at least twice this load. This is because the restorations placed in the oral cavity undergo a decrease in strength over time of approximately 50% of the initial value, so when they are placed in the mouth, must have an initial value of strength of about twice of the majority of forces that on average develop in the that areas. So the threshold of 1000 N is very important and has been widely verified that both Zirconia and PEEK FPD framework exceed this limit. Hence both Zirconia and PEEK can be used as a framework material in anterior Fixed Partial Denture.

In a study done by Zahran et al., (20) reult shows that the mean fracture loads of Zirconia crowns were 1459 N. In a study done by Manoharan et al., (21) the mean fracture load of Zirconia group was 2077 N. 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 reason is that, in some studies procedures for artificial aging (thermal and mechanical cycles) were implemented while in other studies it was not. The artificial aging procedures are intended to simulate conditions which are to establish the patient's mouth that is continuous mechanical stresses and temperature changes of some significance that in time lead to a substantial decrease in the strength of the prostheses.

All Zirconia-ceramic framework fractured involving the whole thickness of the ceramic crown. This is the expected mode of fracture for all ceramic material (27). 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 three-unit FPD made of PEEK. Both studies have investigated the fracture strength in posterior region. Vahideh Nazari et al in 2016 compared the fracture strength of bilayered Zirconia and PEEK framework veneered with composite. He concluded that at given load the fracture that occurred in zirconia involved both framework and veneering material where as in PEEK only the veneering material fractured and the framework remained intact which supports this study.

Other study by Bogna Stawarczyk et al in 2013 who investigated the fracture strength of PEEK three-unit FDPs before veneering and showed a mean fracture load of 1383N. However, the PEEK substructure that they used was PEEK whereas in the present study BioHpp PEEK was used which would have been the reason for increased fracture strength.

The fracture strength of PEEK three-unit FDPs on molars found in a manufacturer's material brochure (Scientific Documentation, Invibio), reports an in vitro fracture resistance of 2055 N, which is closer to the values obtained in this study.

However, the connector area, type of cement, thickness of the coping material will also influence the fracture strength of the framework. The strength of an all-ceramic restoration depends not only on the fracture resistance of the material, but also on a suitable preparation design with adequate material thickness. Frameworks for all-ceramic crown and bridges by CAD/CAM have been based upon empirical machine guidelines rather than clinical scientific data. Most of all CAD/CAM systems, the frameworks of the crowns are design to arbitrary thicknesses of 0.4 to 0.6 mm (28-33). Appropriate veneering porcelain thickness and support to minimize internal stress, reduce mechanical failures, and optimize esthetics of the veneering porcelain.

Connector is that part of fixed partial that unites the retainer and pontic. The connector is definitely the weak point of the entire restorations and its size should be adjusted in height and width in order to allow long-term survival of the restoration. In fact, in several studies it was shown that the failure of the restoration is almost always due to a fracture that begins at the gingival portion of the connector.

Study of Studart et al (34) based on the evaluation of some fatigue parameters of the prostheses, found that the size of the connector should be at least 5.7 mm2, 12.6 mm2 and 18.8mm2 for the bridges respectively of 3, 4 and 5 units. Filser et al (35) recommended a minimum connector size of be 6 to 9mm2 and according to Oh et al (36) the connector should be 6mm2 for three unit fixed partial denture. From all these studies it is clear that the connector should not be less than 6.25 mm2 or more. This is valid for 3-unit posterior bridges. The connector area designed in this study fall in the above mentioned values.

In summary, both Zirconia and PEEK can be used for replacing anterior tooth. And also based on the findings in the current study PEEK seem 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.

Limitation of this in-vitro study are as follows: Number of samples used in the study were limited, The study did not evaluate the type of fracture occurred in the framework and The study did not evaluate the type of failure occurred in the framework

In conclusion, the following conclusion were drawn based on the results obtained in the present in-vitro study, which was conducted to comparatively evaluate the fracture strength of 3 unit CAD/CAM framework made up of Zirconia and PEEK cemented using resin cement.

- The mean fracture strength of CAD/CAM Zirconia framework is1862N.
- The mean fracture strength of CAD/CAM PEEK framework is 2563N.
- PEEK is a reliable material to be used as framework for Fixed Partial Denture.

Conflict of interest

None to declare.

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How to cite this article. Mani J, Abraham AP, Anand S, Tharsan R P3 , Mithra RP, Kumar Ravi A. Comparative evaluation of fracture strength of CAD/CAM anterior FPD framework made with zirconia and peek–an in-vitro study. ***Avan Biomed*** 2025; 14: 140-8.

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