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Effect of Design Parameters on Implant-supported Fixed Partial Denture Frameworks Fabricated from Fiber-reinforced Composite and Polyetheretherketone.

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INTRODUCTION

Implant-supported fixed dental prosthesis in different forms can be used predictably to rehabilitate patients with edentulous or partially dentate jaws (1).

Many materials are commonly used for framework construction such as polyetheretherketone (PEEK) which belongs to the polymer group family and identified as "polyaromatic semi-crystalline thermoplastic polymer". PEEK have been used both in tooth-supported crowns, FPDs and in implant-supported prostheses due to its lower cost and relative esthetic properties compared to metallic framework. PEEK's polymer molecular chain configuration provides enhanced physical and mechanical properties (2).

Fiber-reinforced composites (FRCs) are a group of non-metallic biomaterials that were first used in dental applications in the early 1960s. Since then, it has been used in a variety of disciplines, such as removable and fixed prosthodontics (3,4).

In this study, the null hypothesis was proposed that no significant difference was present in the stress distribution and load/displacement behavior for two different framework materials with different connector designs and different connector cross sectional areas of implant supported fixed partial denture framework.

So, the current study aims to study the stress distribution using finite element analysis of the tested framework materials and designs and study the bending load/displacement behavior using finite element analysis of the tested framework materials and designs.

MATERIALS AND METHODS

In this study, 3D designs of bone block, two abutments (lower first premolar and first molar(representing the abutment and their supporting bone) were designed in AutoCAD computer software. The abutments were designed according to manufacturer's standards. A 14 mm distance was adopted between centers of the abutments (resembling the distance between the selected teeth), the bone block design was a cuboid with 25 x 14 x 15 mm dimensions. The resulting base model consists geometrically of: bone and two abutments (5). The designs were exported as (*.stl) extension files to be accepted by the dental milling and were milled using wax block and casted into Ni-Cr basic model as shown in Figure (1).

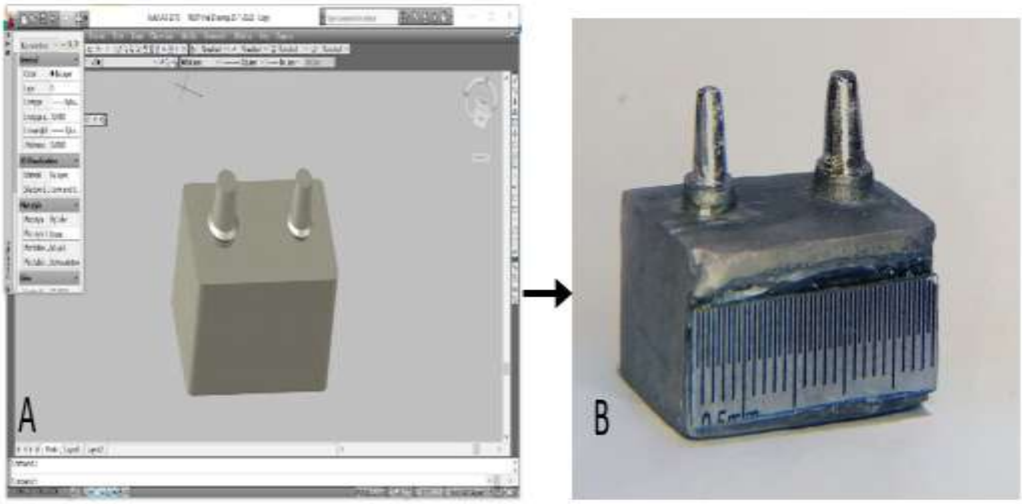


Figure (1): The digital base design milled into Ni-Cr alloy model
(A) The base design in AutoCAD program (B) The finished Ni-Cr base model.

A fixed partial denture framework was designed to fit the previously mentioned base. These designs were drawn according to the manufacturer's instructions of the invistigated materials. The connector part of the framework for the drawn design was further edited to obtain 3 different proposed framework designs with 2 different cross-sectional area (12mm^2 and 16mm^2). These 12 designs were exported as (*.stl) extension files to be milled into two different framework materials (PEEK and FRC)by dental milling machineto be eventually tested for deflection under load, as shown in figure (2).

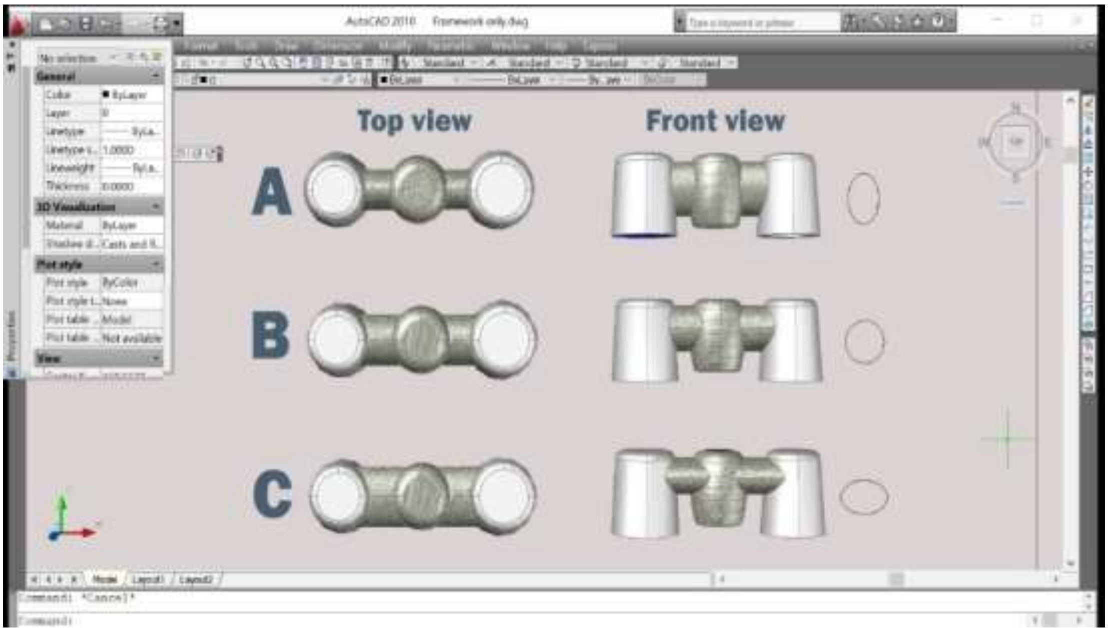


Figure (2):3 different connector designsof different connector cross sectional shape of a fixed partial denture framework drawn using AutoCAD program,**(A)**3:2 H:W Ellipse connector (E3:2), **(B)**Round connector (R),**(C)** 2:3 H:W Ellipse connector (E2:3).

The resulting samples were divided into 12 test groups and were named using letters and numbers that represent their material, connector cross sectional area and connector design, for example: P16E3:2 means **P**EEK framework, **16** mm^2 connectorcross sectional area, **E**llipse connector cross section, **3:2** height to width ratio, as shown in Figure (3).

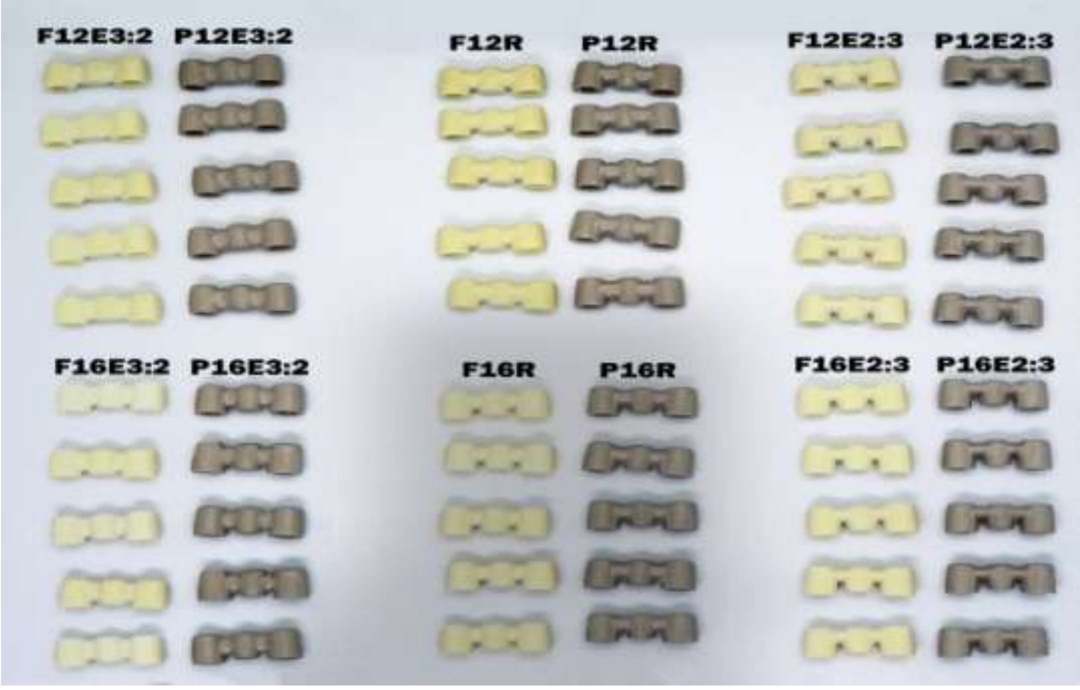


Figure (3): 60samples of the selected designs subdivided into 12 groups according to material, connector cross sectional area and connector shape and height to width ratio.

The test was conducted on Ni-Cr abutments, the samples were fit without cementation to standardize samples and to avoid the effect of adhesive bond strength on the biomechanical behavior of the restorations (6-8) as shown in Figure (4).

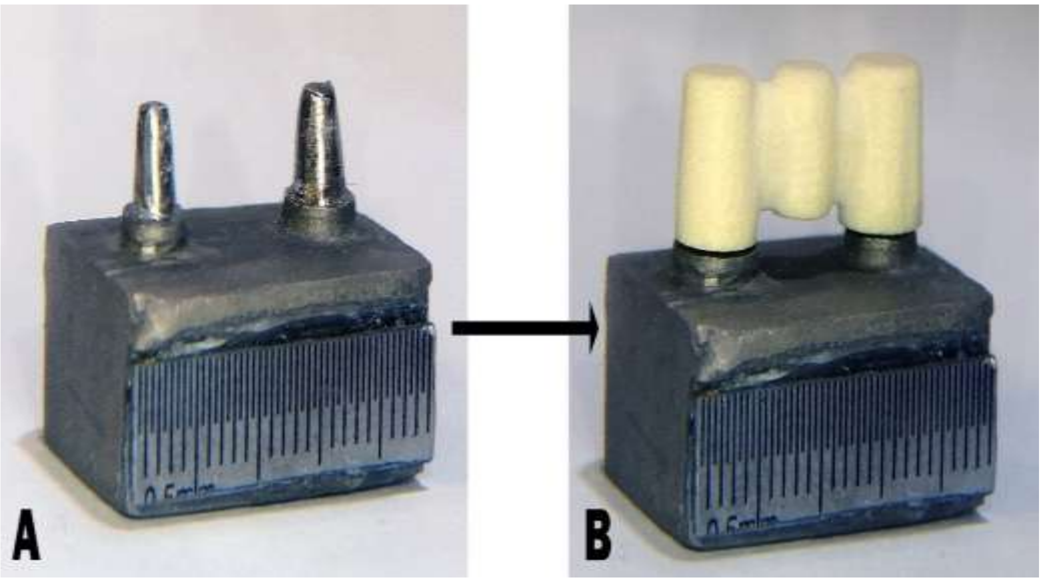


Figure (4): The test assembly (A) Ni-Cr base model with abutments (B) the tested framework seated on the Ni-Cr base model.

After framework seating, the base model with the seated framework was placed on the lower compartment of the Universal Testing Machine (Gester, China).The load was compressively applied at the middle of the occlusal surface of the pontic by a metallic rod with its tip being attached to the upper movable compartment of testing machine. The tip was separated from the FPDs with a rubber sheet to avoid contact damage during loading, The tip was 3.6 mm in diameter and travelling at a cross head speed of 1mm/min (9,10), as shown in Figure (5).

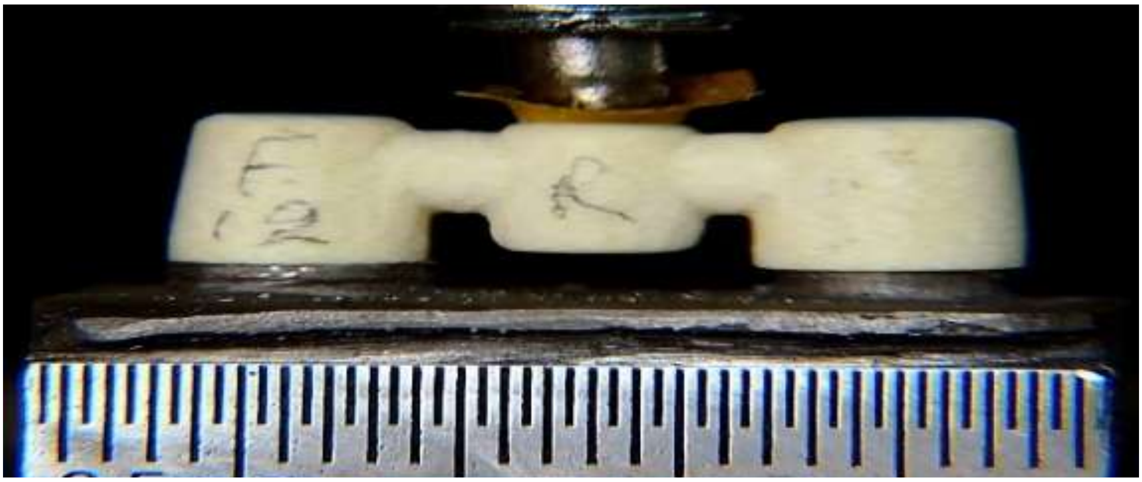
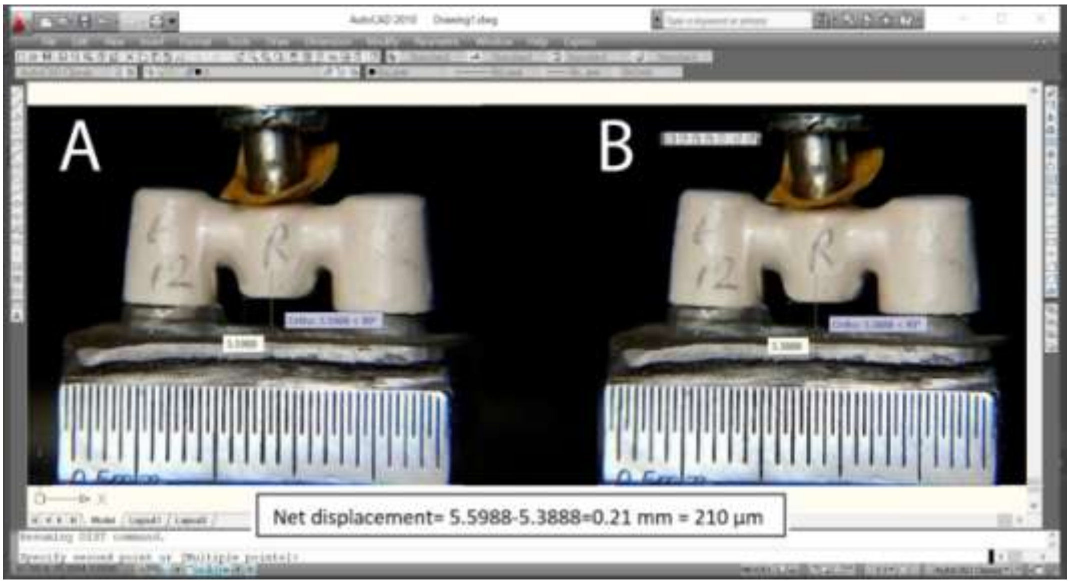


Figure (5): The test assembly mounted on the Universal Testing Machine with a rod attached to the upper compartment and applied on the center of the pontic.

The applied load was recorded in Newton (supplied by the UTM). Two images of each sample were sent to AutoCAD to calculate the amount of displacement, the first one was at zero load and the second one was at 800N load, which is considered the maximum load at molar region (11). A known scale was placed on the base model to be used to calibrate the images. The displacement was measured by calculating the distance between a fixed point on the base and the inferior border of the pontic, the second reading (the smaller value) was subtracted from the first one (the greater value) to find the net displacement (12-15). The displacement was recorded in micrometer, all results were tabulated and grouped to be statistically compared and analyzed, as shown in Figure (6).



Net displacement= 5.5988-5.3888=0.21 mm = 210 µm

Figure (6): The displacement measurement by comparing two images for the test assembly using AutoCAD program (A) distance at zero load (B) distance at 800N load.

The obtained values of this study were recorded, tabulated and introduced into (SPSS, version 26) to be statistically analyzed using independent sample t test and One way analysis of varainces (ANONVA) with Duncan’s multiple range.

RESULTS

The displacement under load values for the 12 selected groups (60 samples) were introduced into SPSS statistics software for statistical analysis of the data and submitted to the Kolmogorov-Smirnov normality test and there was normality of the values.

The effect of framework material on practical displacement:

For the effect of framework material on the amount of displacement under load of different framework groups, six repeated independent samples t tests showed that PEEK groups had significantly higher displacement than FRC groups at ($p \leq 0.05$) for each specific connector design and cross-sectional areas, as shown in Figure (7).

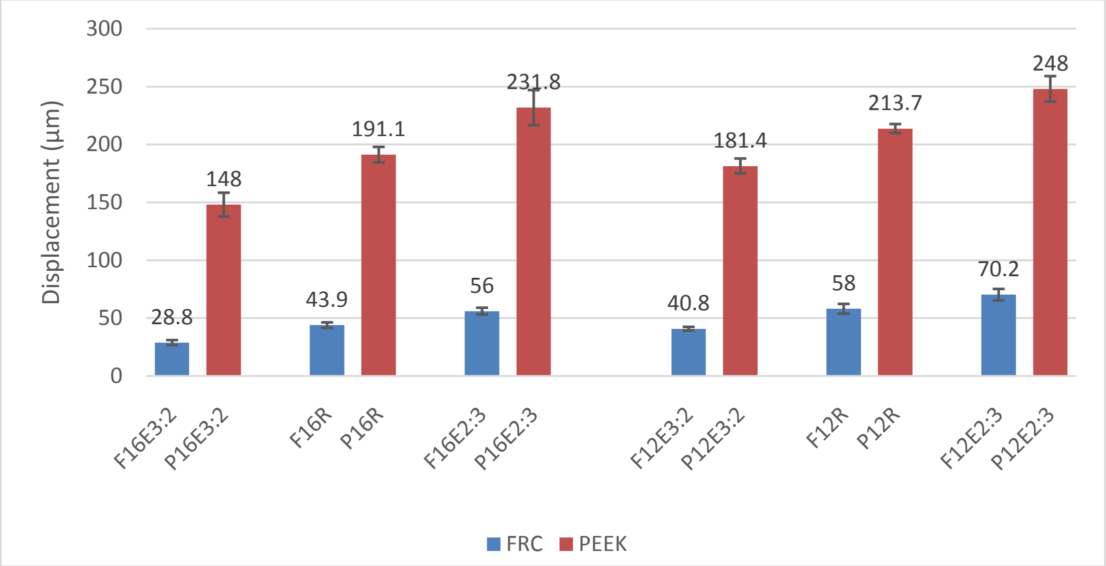


Figure (7): Displacement means for the effect of two different framework materials (PEEK and FRC) on displacement(µm).

The effect of connector cross sectional area on practical displacement:

For the effect of framework connector cross sectional area on the amount of displacement under load of different framework groups, six repeated independent samples t tests showed that $12mm^2$ connector cross sectional area groups has significantly higher displacement than $16mm^2$ connector cross sectional area groups at ($p \leq 0.05$) for each specific framework material and connector design, as shown in Figure (8).

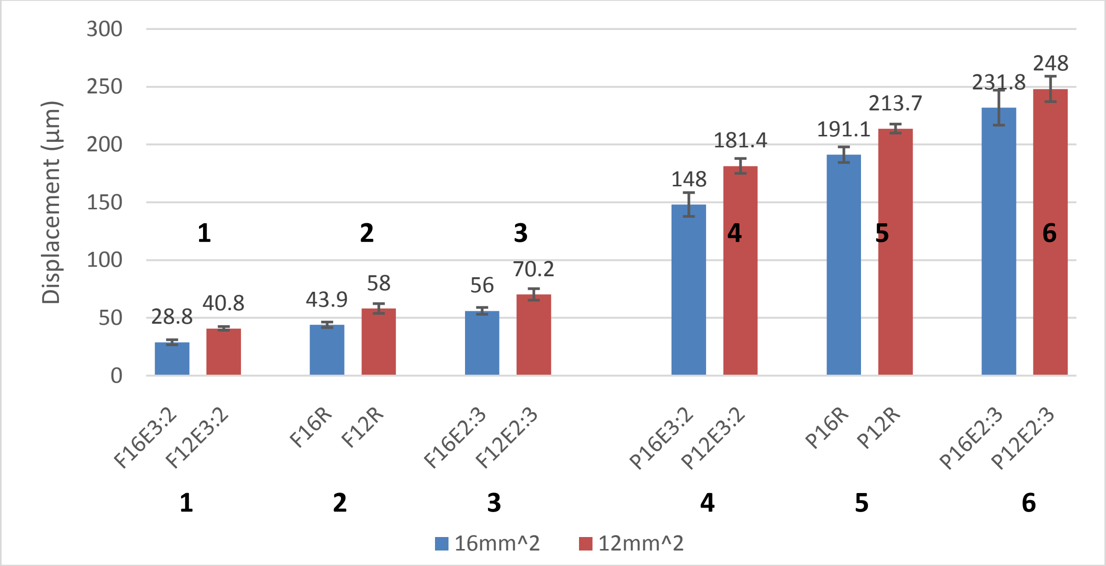


Figure (8): Practical displacement means for $16mm^2$ and $12mm^2$ connector cross sectional areas.

The effect of connector design on practical displacement:

Regarding the effect of framework connector design on the amount of displacement under load of different framework groups, four repeated one-way ANOVA and Duncan's multiple range tests wereperformed and showed that there was significant difference among groups at ($p \leq 0.05$) , the 2:3 height to width ellipse design has the highest displacement, whereas the 3:2 height to width ellipse connector design has the lowest displacement, as shown in Tables (1) and Figure (9).

Table (1): One way ANOVA test for the effect of three different framework connector designs.

ANOVA		
Target groups	**F**	**Sig.**
P16E3:2, P16R, P16E2:3	69.23	.000
P12E3:2, P12R, P12E2:3	93.35	.000
F16E3:2, F16R, F16E2:3	145.46	.000
F12E3:2, F12R, F12E2:3	72.65	.000

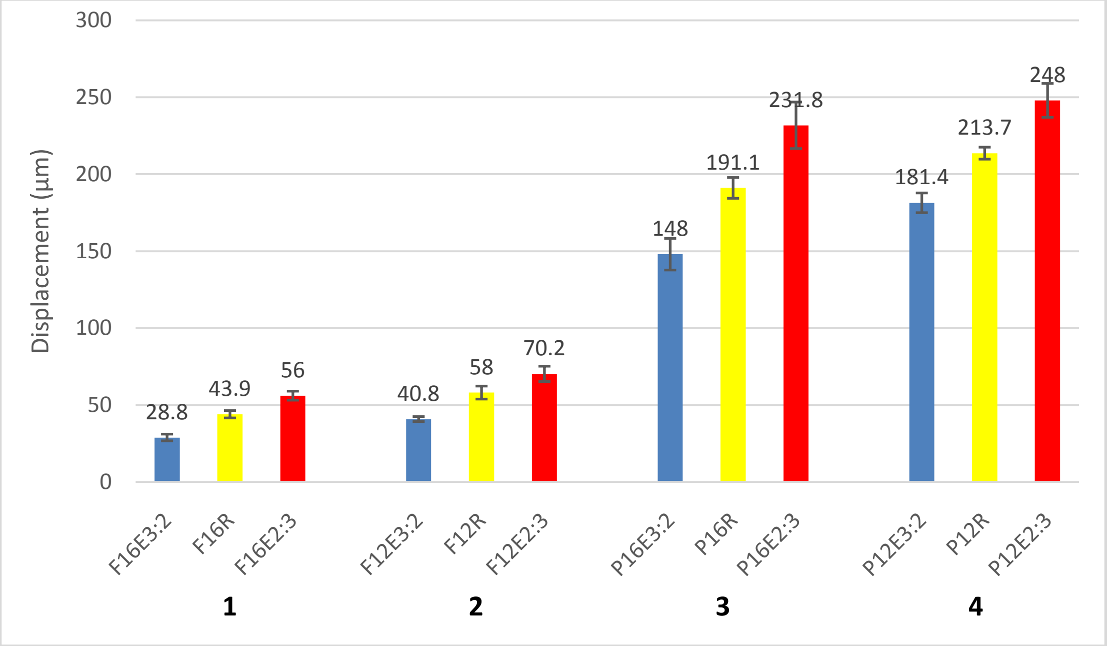


Figure (9): Displacement means for the effect of three different framework designs on displacement (µm).

DISCUSSION

As a result of ongoing biomaterials research, PEEK and FRC can be engineered today with a wide range of physical, mechanical, and surface properties, depending on their application $^{(16)}$.

Although the materials are widely evaluated in orthopedic, periodontology and dental implantology, published peer-reviewed studies evaluating these materials as a cost-effective and biocompatible material for three-unit FDPs or other lab work are still scarce $^{(17)}$.

Therefore, the current study has conducted in vitro tests for evaluating the effect of these materials on framework resistance to displacement under load with different connector designs and cross-sectional areas, to allow screening of PEEK and FRC as potentially suitable materials in the latter application.

Displacement results

The displacement values were obtained from the lower point of the pontic for all samples, this was done to standardize the readings among samples and to avoid the local faulty displacement at the loading point due to localized concentrated compression (indentation) $^{(18)}$.

Effect of framework material

One of the main aims of the current study was to evaluate the effect of different framework materials on displacement under loading, and it was found that the load displacement of PEEK frameworks was significantly higher than that of

FRC frameworks for all cross-sectional areas and designs as shown in and Figures (7).

This can be explained by the fact that the elastic modulus of FRC with its cross-linked polymer matrix is higher (26 GPa) than the elastic modulus of PEEK (3.6 GPa) and that the lower elastic modulus of the framework material generated a larger bending of the prosthesis under functional loads (16,19,20).

Because of this feature, FRC frameworks allows smaller connectors and thinner crowns to be used compared with PEEK (21).

This finding was consistent with other studies that found an increase in framework flexibility when using materials with lower elastic modulus (22,23).

Therefore, the first part of the null hypothesis which stated that there is no significant effect for the investigated framework materials on the amount of displacement under loading was rejected.

Effect of connector cross sectional area

the effect of two framework connector cross sectional area on displacement under loading, it was found that the load displacement of 12mm^2 frameworks was significantly higher than that of 16mm^2 frameworks for all designs and both framework materials as shown in and Figures (8) which is related to the fact that increasing the connector cross sectional area for a specific cross section geometry increases the value of (I) and eventually produces less displacement under load (11).

In order to improve the prognosis of FPD restoration, it is desirable to make the cross-sectional area of the framework connector as large as possible, regardless of the material used. Clinically, however, an excessively large cross-sectional area in an FPD connector is undesirable from the viewpoints of morphology and esthetics (24).

This finding was in approval with other studies which concluded that increasing the connector cross sectional area has a favorable effect on the framework resistance to fracture and displacement (17,21,24).

Therefore, the null hypothesis which stated that there is no significant effect for the framework connector cross sectional area on the amount of displacement under loading was rejected.

Most material manufacturers provide the recommend minimum connector cross sectional area for each specific clinical indication to achieve optimum mechanical properties for the prosthesis, however, another important geometrical factor is the shape and distribution of the area, i.e. height to width ratio of the connector for a given cross sectional area.

Effect of connector design

For the effect of three framework connector designs on displacement under loading, the study showed that frameworks with elliptical 3:2 height to width connectors had the least amount of displacement under load for both framework materials and connector cross sectional areas as shown in Table (1) and Figure (9). This is illustrated in the theory of deflection of a beam, where the height cubed is inversely proportional to the deflection. Therefore, increasing the height will increase (I) exponentially.

The manipulation of connector height is limited to the available space which decreases posteriorly whereas the load increases. Considering the mean available space (height) is 3.6 mm in the posterior and 4.4 mm in the anterior region to allow sufficient veneering thickness of the framework (25).

The design and dimension of the connectors of the implant supported fixed partial dentures may be the key factors that cause fractures, particularly in patients with limited inter-arch spaces and higher occlusal loads that impedes the management of connector height (26).

All previously mentioned interpretations consider ideal vertical loading conditions, this may differ for different loading angles due to the relative change in cross sectional design (27).

This study agrees with other studies which found a significant effect of connector design on bending resistance of the framework and that the higher the loads the framework will be exposed to, the greater the height of connector required (25,28,29).

These results however disagreed with the results found in another study that resulted in no significant effect for the cross-sectional shape of the connector that was designed to assume a circular or oval shape with a height/width ratio of, 3:4, or 2:3, this could be due to the different methods and different test parameters (26).

Therefore, the null hypothesis which stated that there is no significant effect for the framework connector design on the amount of displacement under loading was rejected.

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Statement of problem: Mechanical properties are crucial for the long-term clinical success of implant-supported fixed partial dentures. Selecting new restorative materials should ideally be based on clinical evidence. However, in vitro testing of dental materials is a good alternative to assess their properties and comprehend their behavior. **Purpose:** The purpose of this study was to evaluate and compare different designs of implant-supported fixed partial denture frameworks fabricated from fiber-reinforced composite and polyetheretherketone. **Material and Methods:** 6 framework digital designs made using AutoCAD program were milled to FRC and PEEK samples, these designs had included 3 different connector designs according to cross sectional shape and height to width ratio as follows: (ellipse 3:2, round, and ellipse 2:3) with 2 different connector cross sectional areas (12mm^2 and 16mm^2) and were milled using two different materials (PEEK and FRC) resulting in 12 different groups, 5 samples for each group (n=5). The resulting 60 samples were tested for displacement under 800N load using universal testing machine. The displacement values were recorded by comparing two calibrated images before and after load using AutoCAD computer program. The results were tabulated according to the selected grouping and statistically analyzed using independent sample t test and one way analysis of variances ANOVAwith Duncan's multiple range test to evaluate the effect of framework material, connector cross sectional area and design on displacement. **Results:** The displacement results showed that FRC frameworks exhibited higher resistance to bending than PEEK frameworks for all groups. 16mm^2 connector cross-sectional area resulted in higher resistance to loading than 12mm^2 connectors. Ellipse connectors with 3:2 height to width designs also resulted in the highest resistance to bending compared to other designs. **Conclusions:** Framework design should be considered to allow safe usage of PEEK and FRC as framework materials, FRCframework are more resistance to bending, increasing the height of the connector increases the resistance to bending thus making ellipse designs with higher height to width ratio better in resistance to bending.

CLINICAL IMPLICATIONS

Traditionally, fixed partial denture frameworks can be constructed using metal alloys orzirconia materials,but no current consensus has been published as to other treatment option using fiber reinforced composites or polyetheretherketone as framework material that fulfill some mechanical properties and esthetic properties that are not provided by the traditional framework materials.

CONCLUSIONS

Within the limitation of this study, the following points could be concluded:

1. Framework design and dimensions should be considered to allow safe usage of PEEK and FRC as framework materials in fixed partial dentures (FPD).
2. FRC framework are more resistance to displacement than PEEK frameworks.
3. Increasing framework connector cross sectional area increases resistance to bending of the framework.
4. Increasing the height of the framework connector in relation to the width increases the resistance to bending, even if the cross-sectional area is the same.
5. The ellipse design with 3:2 height to width (E3:2) had the highest resistance to bending.

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