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# EVALUATION OF FRACTURE RESISTANCE OF LONG SPAN IMPLANT SUPPORTED FIXED DENTAL PROSTHESES FABRICATED FROM DIFFERENT CAD/CAM MATERIALS

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## *ABSTRACT*

**Objective:** Implant prosthetic materials capable of reducing mechanical stresses on the implants and supporting structures in case of long span implant supported FDPs are highly required. The purpose of this study was to evaluate the fracture resistance of CAD/CAM long span implant supported fixed dental prostheses fabricated from PEKK compared to PEEK and zirconia. **Material and methods:** Two implants with straight abutments were inserted in a metal model representing lower first premolar and second molar. Twenty-one frameworks of four-unit FDPs were fabricated on the master model from three materials; Polyetheretherketone (PEEK), Polyetherketoneketone (PEKK) and Zirconia, and divided according to type of material into three groups (n = 7). The cemented frameworks were loaded until fracture by using computer controlled universal testing machine (Modcl 3345; Instron, USA) with a 5 KN load cell. The load at failure manifested by an audible crack and confirmed by a sharp drop at load-deflection curve recorded using computer software (Instron Blue hill Lite Software) and this value was recorded in Newton. **Results:** The mean fracture resistance values were [612.31±27.41N], [334.44±20.54N] and [1334.20±176.71N] for the PEEK, PEKK and Zirconia groups respectively. There were statistically significant differences between the three material groups. **Conclusion:** The fracture resistance values of the long span implant supported FDPs were affected with the material type. All the values obtained in this study fall above the mean masticatory force value in the posterior region with caution in PEKK design.

**KEYWORDS:** PEEK, PEKK, Zirconia, Framework, Fracture resistance.

## INTRODUCTION

Implant dentistry has a unique goal of restoring the patient to normal function, esthetics, speech, comfort and health regardless the condition of the stomatognathic system. Prosthetic therapy for missing teeth has improved significantly thanks to the development of dental implants and the evolution of CAD/CAM technology. The choice of prosthetic materials, on the other hand, is an important factor of implant prostheses' long-term clinical success and stability. [1,2] CAD/CAM technologies are capable of providing standardized and efficient dental restorations and can be used to process a variety of dental materials such as ceramic, zirconia, composite, and acrylic resins.[3, 4]

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Due to the high chemical, mechanical, physical, and optical characteristics, as well as good clinical success even in the posterior region, zirconia was developed as an aesthetic substitute for metal ceramic implant restorations.[5] In 2012, all ceramic crowns were shown to have mechanical features close to metal ceramic crowns, thanks to technological and material improvements in Zirconia cores. [6, 7]

Polyaryletherketones (PAEK) are high-performance thermoplastics which have high strength, stiffness and good resistance to hydrolysis. Polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) both belong to the PAEK family. [8] PEEK is a high-performance material that has piqued the interest of dental scientists. [5, 9] It offers a wide range of mechanical and chemical qualities that can withstand high temperatures. It has a Young's modulus of (3.6-4.1 GPa) and a tensile strength of 90-100 MPa.[10, 11] PEEK melts at about 343°C and has a glass transition temperature of about 143°C. [12] It also has a great resilience to heat and biodegradation. PEEK possesses good cell biocompatibility, radiolucency, and mechanical characteristics that are comparable to cortical bone of human.[10] In dentistry, PEEK is utilized for abutments RPD frameworks and FDP frameworks The polyetherketoneketone (PEKK) is the most recent PAEK generation. PEKK has both amorphous and crystalline characteristics, providing it unique mechanical, physical, and chemical capabilities. It also has about 80 percent greater compressive strength than PEEK, making it suitable for a wider range of applications.[8]

Milling has several advantages, including the removal of porosities caused by human error and the elimination of casting defects through precise milling of frameworks. [13] The general adaption of the final restorations is largely determined by the coping (framework). [14-16] For premolars, the suggested total occlusal convergence angle (10º-20º) and the minimum height of 3.0 mm. [17, 18]

Restoration failures are frequently caused by a combined factors of biologic, aesthetic, and mechanical failure.[19] The physical science of evaluating a material's resistance to distortion or fracture under an applied force is known as fracture resistance. Fracture resistance is affected by a variety of factors, including material composition, fabrication technique, occlusal thickness, restoration type, and die material form and type. The luting agent has an effect on the fracture resistance test, regardless of the cement thickness or type. The fracture resistance is affected by the storage medium, periodontium simulation, and antagonist type, in addition to the amount, direction, and frequency of the load. One of the most critical aspects that affect the fracture test is thermocycling and mechanical ageing.[20]

Several studies measured the fracture load of zirconia restorations, the results were between (897-2489 N). [5, 21-33] Multiple studies evaluated the fracture load of PEEK restorations, the results were between (802-3132 N). [5, 28, 32-37] Several studies evaluated the fracture load of PEKK restorations, the results were between (310-2037N). [29, 33, 38, 39]

In the posterior region, the average masticatory force is 300 N.[40] The length of the bridge determines the amount of stress in the prosthesis..[41] As a result, longer restorations are likely to face higher tensile stresses, particularly when employed in high-stress regions like the posterior region. The occlusal forces in FDPs are passed to the surrounding structures via pontics, connectors, and abutments, with the connector region experiencing the most stress. [42-44] In both in vitro and in vivo tests, fracture of the connections was found to be the only form of failure in all ceramic FDPs. [45, 46] As a result, connectors dimensions play a critical role in fracture resistance. [47] Studart et al[48] showed that the connector size should be at least 5.7 mm2, 12.6 mm2, and 18.8 mm2 for bridges of 3, 4, and 5 units, respectively, based on the measurement of some fatigue measures of the prostheses. For three-unit FDPs, Filser et al[49] recommended a connecting size of 6 to 9 mm2, while Oh et al[50] recommended a connector size of

6 mm2. Larger connector size would have likely increased fracture resistance as well. [51]

The mode of failure varies depending on the material. Zirconia shows a brittle fracture form where the fragments are completely aligned along the fracture line.[52] Deformation of the framework in PEEK, particularly at the middle connector. [32] The gingival area of the middle connector in PEKK developed a severe crack. [29, 53]

There are limited data comparing the fracture resistance of PEEK, PEKK and zirconia Therefore; the null hypothesis to be tested in this study is that the material type will not affect the fracture resistance of the long span implant supported FDPs.

## METHODOLOGY

Materials used in this study: The materials are indexed in table (1).

Sample size: Based on earlier study[54], a sample size of 7 in each group has an 80 percent power to detect a difference in means of 169.87 with a significance level (alpha) of 0.05 (two-tailed) at 95 percent confidence intervals. The P value was less than 0.05 (two-tailed) in 80 percent (the power) of those studies, indicating that the results were statistically significant. The difference between means was statistically non-significant in the remaining 20% of the experiments (Reported by GraphPad StatMate 2.00).

**Preparation of bridge specimens:**

Specimens grouping: A total of twenty-one frameworks[34, 55] of four-unit FDPs were divided according to type of material into three groups (n=7). Group PEEK, Group PEKK and Group Zirconia.

Fabrication of master models: Aluminum model (Length= 50mm Width=30mm Thickness=20mm) was cut from aluminum bar. Two holes were drilled in the model to receive the pre-determined implants. The two implants were fixed in the holes using auto-polymerizing acrylic resin (Size (Ø 4.3mm, L 13mm) representing lower 1st premolar; tooth No, 34 and Size (Ø 5mm, L 13mm) representing lower 2nd molar; tooth No, 37). The distance between the apices were 23 mm[56], corresponding to the average distance between a first premolar and a second molar. To adjust parallism and distance, A special paralling device was designed to hold the two implants parallel to each other. A dental surveyor (Paraskop®M, Bego, Bremer, Germany) was used to control the horizontal and axial orientation of the inserted implants and to centralize them within the resin material in the holes placed in the model. Using a milling machine, each Abutment was reduced to 4 mm height, 16$^{o}$ total occlusal convergence and radial shoulder finish line with (0.8mm) thickness. The abutments were then adapted over their implants and tightened precisely. All frameworks were directly fabricated on this model. (Figure:1)

**TABLE (1)** Materials used in this study:

| Material | Product | Lot No. | Manufacturer |
|---|---|---|---|
| Implants:<br>-Size (Ø 4.3mm, L 13mm)<br>-Size (Ø 5mm, L 13mm | JD Evolution®Plus+ | 02-08-20-5520<br>05-07-18-3318 | JDentalCare srl Via del Tirassegno 41/N41122 Modena Italy |
| PEEK Milling blank | BreCAM.BioHPP | 484123 | Bredent GmbH&Co.KG Weissenhorner Str. 2, 89250 Senden - Germany |
| PEKK Milling blank | Pekkton@ ivory | 0000359831 | Cendres+Métaux SA Rue de Boujean 122 CH-2501 Bie1/Bienne, Switzerland |
| Low translucent zirconia | Ceramill Zl White | 1802002 | Amann Girrbach AG Herrs chaftswiesen 16842 Koblach Austria |

**Framework fabrication:**

***Scanning the master model:*** Before scanning, the master model was sprayed using (D-Scan) Spray (Dentify GmbH Germany) and ensured to form a single continuous layer, then mounted to the base of the scanner. Optical impression was then taken using lab scanner (CS.Neo - 3D Dental Scanner(CAD star Technology GmbH Austria)). The model was fixed to the base of the scanner, then the scan was initiated. The scanned 3D model was generated directly through (CS.Core dental scan application version 2.0.15 (CAD star Technology GmbH Austria)). The scanning process produced a 3D model that was ready for design.

***Framework designing (CAD):*** The framework was designed using EXOCAD software (Exocad (exocad GmbH) Germany). The constructed 3D model was transferred to the program to start the designing process. Only one design was used with all materials in this study. Path of insertion detection, teeth selection, the material thickness was set to (0.8mm), connector size was set to (14mm) and cement gap was set to 80$\mu$m, as observed in the diagram (Figure:1)

***Milling of the frameworks (CAM):*** The designed framework was then set up in the milling blank using MILL BOX software (CIMsystem, Via Monfalcone, (MI) Italy). The material was selected and then 7 frameworks for each group were set up within the corresponding blank and then milling was done by five axis milling machine (COREiTEC 250i Series (imess-icore GmbH, Germany))

***PEEK & PEKK Groups milling:*** fabrication of long span bridges from PEEK and PEKKTON blanks started from opening the MillBox software, then selection of material, selection of blank, nesting and then milling.

***Zirconia group milling:*** The same steps used with PEEK and PEKK were followed with the zirconia group, but differ here by adding shrinkage factor recommnded by the maniufacturer to the nesting process.All the milled zirconia frameworks were then placed on the firing tray on their occlusal surfaces and away from the margins and then sintered in (TABEO-1/M/ZIRKON-100 (MIHM-VOGT GmbH & Co. KG, Germany)) sintering furnace. The sintering program was set according to manufacturer instructions for long span bridges 10h with an average rise in temperature of (8˚C/min) and peak temperature of (1450˚C) with a holding time of (2h) and slow cooling rate of (-5˚C/min).

**Cementation of the frameworks**

Surface treatment of PEEK and PEKK frameworks: The fitting surfaces were sandblasted with 110 $\mu$m and 2-3 bar (0.2-0.3 MPa) pressure at a distance of 10mm and 45degree angle, then cleaned, rinsed and air dried. Visio.link primer (Bredent GmbH&Co.KG,Germany) was applied followed by polymerization with a light polymerization device (220 Mw/cm2) for 90 seconds (bre.lux Power Unit, Bredent GmbH&Co.KG,Germany) in accordance with the processing instructions.

Surface treatment of Zirconia frameworks: The fitting surfaces were sandblasted with Al2O3 (50$\mu$m) at 1 bar (0.1MPa) maximum pressure for 10 seconds at a distance of 10mm and 45degree angle, then cleaned, rinsed and air dried. One to two coats of MKZ primer were applied uniformly wetting the bondable surface then dried with an air syringe for 3-5 seconds.

**Application of adhesive resin cement:[57]**

DTK-Kleber adhesive resin cement (Bredent GmbH&Co.KG,Germany) was applied on the fitting surfaces of the frameworks and then, they were seated on their respective abutments. To prevent framework movement and maintain accurate positioning, the loading device was used to apply a uniform load of 49 N[58] for 10 minutes. The excess cement was gently removed with a brush prior to spot curing the margins for 2-3 seconds per surface. After excess cement has been removed each surface of the restoration was cured for up to 40 seconds using light curing device.

**Fracture resistance evaluation:**

The cemented frameworks were loaded until they fractured using a computer-controlled universal testing machine (Instron Modcl 3345, USA) equipped with a 5 KN load cell, and the data was recorded using computer software (Instron Bluehill Lite Software). All samples were separately installed on the universal testing machine's lower fixed compartment and secured with a screw. A tin foil was placed between the load piston and the specimen to ensure equal stress distribution and minimization of the transmission of local force peaks.

Fracture test was done by compressive mode of load in the universal testing machine applied occlusally using the loading piston (a vertically movable rod with a semi-spherical head 8 mm in diameter) that was mounted directly over the center of the framework at connector between the pontics at cross head speed 1 mm/min until fracture occurred. The load at failure was validated by a sharp decline in the load-deflection curve obtained using computer software, and this number was recorded in Newton.

Failure mode (Figure:2): Regarding PEEK group, plastic deformation (bending) of the framework especially at the middle connector. No separation of the fragments was observed in any of the specimens. In PEKK group, deep crack started at the gingival portion of the middle connector or bulk fracture occurred with mild plastic deformation moments before fracture. Zirconia group showed a brittle fracture (bulk fracture) middle connector in which the fragments perfectly fitted to each other along the fracture line.

**Statistical analysis of the data:**

Data was recorded on a computer software and evaluated with IBM SPSS version 20.0 software. (IBM Corporation, Armonk, NY) The Kolmogorov-Smirnov test was employed to ensure that the distribution was normal. Range (minimum and maximum), mean, standard deviation, and median were used to express quantitative data. The significance of the acquired results was assessed at a 5% level of significance.

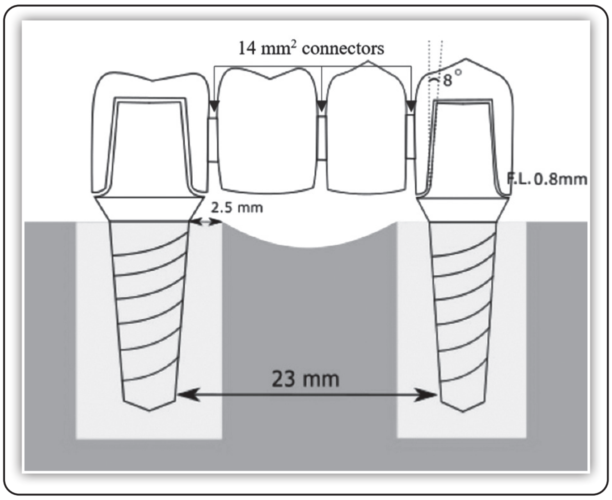


FIG (1) Diagram showing master model with the framework design

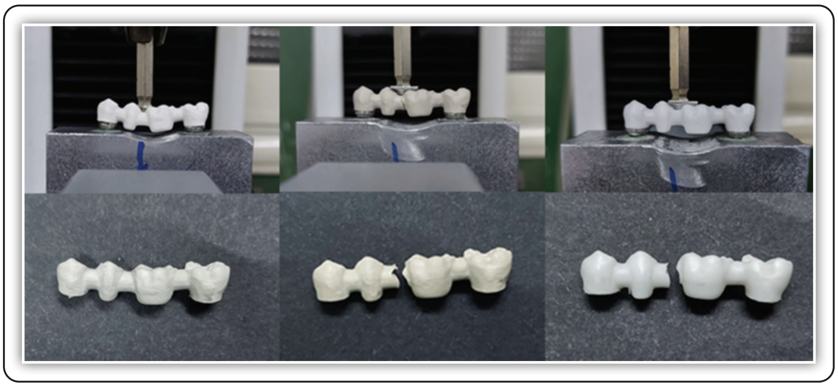

FIG (2) INSTRON universal testing machine and Failure mode of the three tested materials. From left to right; PEEK, PEKK and Zirconia respectively.

## RESULTS

Effect of tested materials on the fracture resistance (One-way ANOVA): (Table: 2)

**TABLE (2)** Mean and standard deviation of fracture resistance for different tested materials.

| | PEEK | | PEKK | | Zirconia | | p-value |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | |
| Fracture | 612.31[b] | 27.41 | 334.44[c] | 20.54 | 1334.20[a] | 176.71 | <0.001* |

**=Significant. NS=Non-significant Different letter within each row indicates significant difference*

The mean fracture resistance values were [612.31±27.41N], [334.44±20.54N] and [1334.20±176.71N] for the PEEK, PEKK and Zirconia groups respectively. There were statistically significant differences between the three material groups. (Figure:3)

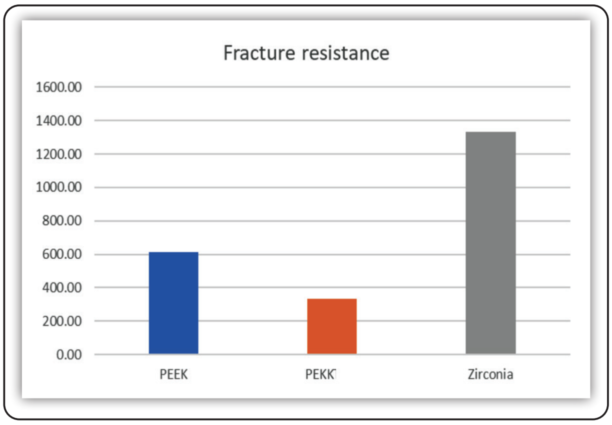


FIG (3) Bar chart showing the mean fracture resistance for different tested materials.

## DISCUSSION

The null hypothesis that tested in this study, which was the material type will not affect the fracture resistance of the long span implant supported FDPs was rejected.

Biologic, aesthetic, mechanical, or a mixture of factors could cause the FDP to fail. Restoration failures are frequently caused by a combination of factors. [19] Since their appearance in the 1960s, metal-ceramic restorations stayed the 'gold standard' in prosthodontics.

All ceramic crowns were shown to have mechanical characteristics comparable to metal ceramic crowns due to technological and material improvements in Zirconia core[6, 7]

The length of the bridge seems to be related to the stress intensity in the prosthesis.[41] As a result, longer restorations are likely to face higher tensile stresses, particularly when employed in high-stress regions like the posterior region. As a result, the current research concentrated on long span (four unit) posterior bridges.

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

In the present study, the fracture resistance of four-unit implant supported FPDs frameworks fabricated from PEEK, PEKK and Zirconia was assessed and compared in vitro. PEEK and PEKK were fabricated in the form of frameworks. The material cannot be manufactured in an overall shape since it is not aesthetic.[34, 55] The original model with the titanium abutments was scanned, and a fixed design with the same dimensions (the connectors had an almost circular cross-section of 14 mm2 and the wall thickness was 0.7 mm) was used to produce the PEEK, PEKK and Zirconia FDPs framework using the same CAD/CAM system to ensure standardization[34].

Fracture of the connections was shown to be the only mode of failure in all-ceramic FDPs in both in vitro and in vivo studies.[45, 46] According to Kamposiora et al.[41] thin and irregularly shaped elements of the framework, such as the connector region, reach critical strain earlier than thicker areas, such as the pontics and abutments, under loading. As a result, FDPs are predicted to fail in these places that bend more easily. As a result, connector dimensions play a critical role in fracture resistance.[47]

Study of Studart et al[48] based on the evaluation of some fatigue parameters of the prostheses, found that the connector size required to be at least 5.7mm2, 12.6 mm2, and 18.8 mm2 for bridges of 3, 4, and 5 units, respectively. Filser et al [49] recommended a minimum connector size of be 6 to 9mm$^2$ and according to Oh et al [50] the connector should be 6 mm$^2$ for three unit fixed dental prostheses. Greater connector surface area would have likely increased fracture resistance as well.[51] From all these studies the connecter for 4-unit posterior bridges should not be less than 12.6 mm$^2$ or more. The 14 mm$^2$ connector area designed in this study fall in the above-mentioned values.

Cementation of the frameworks was done using DTK-Kleber adhesive resin cement following the clinical protocol to simulate the clinical conditions. Resin cementation provides high retention and act as buffering layer that absorb stresses during load application resulting in higher fracture resistance values.[57] A special loading device was used for Cementation of the crowns in this study as recommended by Gorten et. al. [58] for proper seating over the corresponding abutments with a load of 5 kg directed parallel to the longitudinal access of the implants.

Regarding the treatment with FDPs, it was reported that the occlusal forces are transmitted to the surrounding structures through pontics, connectors and abutments and that the highest stress usually occurs in the connector region [42-44]

In this study, the mean fracture resistance values were [612.31±27.41N], [334.44±20.54N] and [1334.20±176.71N] for the PEEK, PEKK and Zirconia groups respectively. There were statistically significant differences between the three material groups.

Several studies measured the fracture load of zirconia crowns, the results were between (1265-2077 N) [21-25] Kohorst P. et al. [26] investigated the load-bearing capacity of posterior four-unit FDPs and showed a mean value (1263 N). Larsson et al [27] compared the fracture load of four-unit Y-TZP FPD cores designed with different connector diameters showed a result of (897±113)N with 4 mm2 connector surface area. Korsel A M. [31] reported higher fracture resistance load of monolithic zirconia group (1743 ± 283 N) than veneered zirconia group (1273 ± 177 N). The fracture resistance of Zirconia frameworks obtained in this study also ranges within these values.

Several studies investigated the fracture resistance of PEEK; Stawarczyk et al in 2013 investigated the fracture resistance of PEEK three-unit FDPs before veneering and showed a mean fracture load of 1383N. [34] Other study by Stawarczyk et al. assessed the influence of different fabrication methods of three-unit PEEK FDPs on fracture load. The milled CAD/CAM FDPs showed a mean fracture resistance of (2,354±422N), the connector area of the FDPs was set to 16 mm2[35]. Vahideh Nazari et al in 2016 evaluated the fracture resistance of three-unit implant supported FDPs with excessive crown height and presented mean failure loads for zirconia 2086±362N, Ni-Cr 5591±1200N and PEEK restorations 1430±262N.[5] Addullah et al. [36]reported values of 802 N in milled PEEK crowns. Taufall S et al [37] investigated the fracture load of different veneered PEEK 3-unit (FDPs) and showed a mean fracture resistance of (1882±152 N). Hossam et al., **[28] investigate**d the fracture resistance of three-unit FDPs zirconia and PEEK frameworks, zirconia showed a mean value of (1243.51±175.8N), PEEK showed a mean value of (1626.31±191.9N). Latter study by Rodríguez et al. (2021) [32] who compared the fracture load of metal, zirconia and PEEK posterior CAD/CAM FDP frameworks, they used different connector size for each material 9mm$^2$ for zirconia group and 16 mm$^2$ for PEEK group, the mean fracture values for Zirconia group (1859 N) and for PEEK group (3132N). The fracture resistance of PEEK frameworks obtained in this study differ from the reported studies due to several factors which include; difference in the edentulous span, connector size, structure design, and methods In addition, the load value at when the failure began was recorded in the study.

There are limited data revealing fracture resistance of PEKK; The obtained results were in agreement with Mochalski et al., (2021)[39] who did a study to investigate the fracture and fatigue behavior of implant supported bars with distal extension milled from three different materials (titanium, cobalt chromium , and PEKK). The static fracture limit of the three materials was 1,750 N, 780 N, 310 N for Ti, CoCr, and PEKK, respectively. The results were disagreed with the results of the study by El Moughy et al.[38] who reported a mean fracture resistance (2037 N ± 49 N with no fracture), Amelya et al. [29] who reported that PEKK veneered with lithium disilicate presented a higher fracture load (1526 N) than PEKK veneered with composite resin (1069 N) and Türksayar et al., (2021)[33] who reported a mean fracture resistance of the PEKK abutments (541.90 ± 68.49 N). A three-dimensional finite element analysis study done by Lee et al. [59] evaluating a four-implant supported polyetherketoneketone framework prosthesis, they concluded that; the shock absorbing effectiveness of low elastic modulus framework material PEKK was minor and limited only to where compressive stress dominates (higher stresses transmitted with tensile stresses). [1, 59] The rigid framework helps to alleviate stress on the implants and bone. Low elastic modulus framework material puts less stress on the framework itself, but it also puts more stress on the prosthetic structures around it, resulting in lower long-term safety. [59]

The mean masticatory force in the posterior region is 300 N [40] All the fracture values of the used materials fall above this value while PEKK was just above it.

Failure mode (Figure:4): Zirconia group revealed a brittle fracture (bulk fracture) in which the fragments were completely aligned along the fracture line. The breakdown happened at the central connector, indicating that this place had been subjected to the most stress. [32, 52] The force–displacement curves revealed that the fracture propagated quickly without any prior deformation.

Regarding PEEK group, a different fracture form was discovered. [32] A plastic deformation (bending) of the framework especially at the middle connector. There was no evidence of fragment separation in any of the specimens. The force–displacement curves showed that plastic deformation occurred without fracture.

In PEKK group, deep crack started at the gingival portion of the middle connector or bulk fracture occurred with mild plastic deformation moments before fracture.[29, 53] the force–displacement curves showed that mild plastic deformation occurred moments before fracture.

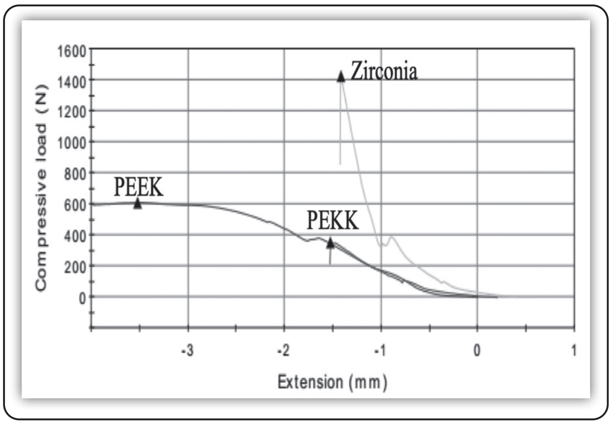


FIG (4) Force-displacement curves, (Note the fracture line in zirconia and PEKK, no fracture line with PEEK)

## CONCLUSION

Based on the findings of this study the following conclusion could be drawn:

- The fracture resistance values of the long span implant supported FDPs were affected with the material type.
- All the values obtained in this study fall above the value of the mean masticatory force in the posterior area with caution in PEKK design.

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