JFCR
Journal of Fundamental and Clinical Research
https://jfcr.journals.ekb.eg/
ISSN 2735-023X
Vol. 3, No. 1, 50-62, June 2023

Fracture Resistance of Three-Unit Implant Supported Fixed Partial Dentures Fabricated from Zirconia and PEEK "An In-Vitro Study"

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ABSTRACT

Background: Selection of prosthetic material is a critical factor affecting implant supported restorations long term success. It influences the transmission of stresses during function that transferred to each prosthetic component. PEEK -poly ether ether ketone-is a quite new polymeric material used for dental applications. It has been introduced for its promising shock absorbing and stress distribution qualities. However, there are limited data available in literature concerning fracture strength of PEEK restorations as implant superstructure. ***Aim of study***: Evaluating fracture resistance of three-unit implant supported fixed partial dentures fabricated from PEEK and monolithic zirconia. ***Materials and methods***: An in-vitro model was fabricated while two implants were embedded in an epoxy resin block simulating a case of missing mandibular first premolar and first molar. A total of 14 Monolithic zirconia and PEEK three unit fixed partial dentures were CAD/CAM (computer aided designing/computer aided manufacturing) fabricated and divided into two equal groups (n=7). Load till fracture was applied with a crosshead speed of 0.5 mm/min using a universal testing machine and fracture resistance was recorded in Newtons(N). Mode of failure was assessed using digital microscope. **Results:** The mean fracture resistance for zirconia was 979N, while PEEK was 920N. Kolmogorov-Smirnov and Shapiro-Wilk tests showed that there was no statistically significant difference between both groups. ***Conclusion:*** PEEK superstructures are considered a new reliable alternative due to its load bearing capacity and fracture strength. PEEK shock absorbing makes it such an innovative approach that can substitute other commonly used materials.

Keywords: Fracture resistance, Implant, Zirconia, PEEK, FPDs.

INTRODUCTION

Implant supported restorations are used nowadays for missing teeth replacement due to great technologies and recent modifications added to the implantology

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sector.[1] Implants can be fabricated from different materials with various expected results from each material, ranging from the standard titanium implant till the modified nano coated implants.[2] Due to certain drawbacks of some materials, new materials are introduced to the market for their superior mechanical properties; however, implants are considered a way for stiff anchorage in bone through a process called osseo-integration.[3,4]

Implant supported superstructure is necessary for long term success and durability of the implant itself in terms of stresses distribution and fracture strength capability.[1] Stresses falling on an implant are too much greater than those applied on a tooth structure with a periodontal ligament offering a degree of elasticity. Various materials are used for implant supported fixed partial dentures construction with different fabrication methods with an advantage from each material.[5] Selection of superstructure material plays a crucial role in how stresses are transferred to the masticatory cycle.[1]

Ceramics as an option are generally considered a patient's first satisfactory option for its translucency, esthetic shades and reasonable fracture strength even if used in high stresses posterior region especially glass-free group of ceramics.[6,7] Although they do not provide ultimate esthetics in comparison to glass containing ceramics, they have high fracture strength if used as restoration supported by an implant. Yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) is used nowadays mainly as an implant supported fixed partial dentures due to its favorable fracture resistance, flexural strength and withstanding high stresses. Zirconia as a restoration have gained great popularity thanks to its high flexural strength which is comparable to steel (ranging from 900-1200 Mpa) that's why zirconia is defined as ‘‘ceramic steel’’.[6]

Zirconia-based restorations lack that translucent vivid effect provided by glass-based ceramics as feldspathic or lithium disilicate ceramics. Zirconia most common reported drawback is its great stiffness, low temperature degradation and stress shielding which is reduction in bone density due to modulus of elasticity mismatch between supporting bone and implant over many years of clinical function.[8] Once there is great mismatch in modulus of elasticity between implant material and surrounding compact or cancellous bone, the expense will be unfavorable concentrated stresses on implant ending up by stress shielding and implant loosening or even failure in some situations. For such drawbacks, a new approach, PEEK, has been introduced to the market.[2]

PEEK, which stands for (poly-ether-ether-ketone), is a semi-crystalline, metal-free thermoplastic polymer. It was first introduced for defective body parts replacement in orthopedics thanks to its low weight, shock absorbing property combined with a four Gpa modulus of elasticity (close to human cortical bone 14Gpa). PEEK has been introduced as a promising alternative for metal ceramic, glass containing ceramics and zirconia restorations thanks to its innovative physical properties such as its (4-5Gpa modulus of elasticity), great wear resistance and up to 2345N fracture resistance. PEEK has been reported having an inert nature with no adverse allergic reactions, low reactivity and water solubility. Bio-Hpp (High Performance Polymer) is a modified type of PEEK with 20% inorganic nano-ceramic fillers adding high abrasion resistance, flexural strength, polishability and constant homogeneity.[8,9] In prosthetic dentistry, PEEK applications vary from interim implant abutments fabrication up to interim restorations, fixed partial dentures and endocrowns whether via CAD-CAM technology or by pressing techniques.[9]

Regarding PEEK's advantages, it resists high temperatures with a 343°C melting point without significant degradation, has less biocorrosion within body fluid, preventing metal ions release that can trigger cytotoxicity, allergy, and inflammation. Due to those advantages, PEEK does not only prolongs the prosthesis life span, but it also protects the abutment teeth from damage. One important property regarding PEEK is its shock absorbing when stressed and its deformability, providing a more balanced stresses distribution, and limiting "stress-shielding" if serving as an implant. PEEK thermal conductivity is lower than that of zirconia. It, thus, protects abutment teeth from thermal fluctuations. It also has a lower wear rate than metal and its alloys. PEEK tensile properties are comparable to that of human teeth, and its low density (1.31 g/cm^3) results in favorable stress distribution for a lightweight framework.[10] PEEK has also been reported being less abrasive than other materials and requires less milling time.[2,11]

Mode of fabrication of PEEK restorations have been reported to have an effect on its load bearing capacity. Frameworks can be fabricated either by milling or by pressing from PEEK pellets or from its granular form.[12] However, CAD/CAM milled frameworks have been reported to have the highest load to fracture resistance if it is to be compared with pressing technique.[12] Fracture resistance and flexural strength are two important mechanical properties that should be provided by FDPs to ensure durability and long term success.[12] Thermocycling is a common thermal aging regimen used to simulate intra-oral temperature fluctuations which can affect restorations long term durability.[13]

Therefore, the aim of this in-vitro study was to evaluate fracture resistance of monolithic PEEK and zirconia used to fabricate implant supported frameworks milled through a subtractive protocol, since fracture resistance is considered an important mechanical property that can affect restorations long term clinical success.

The null hypothesis was that using PEEK implant to support three-units fixed partial denture will not improve fracture resistance compared to monolithic zirconia group.

MATERIALS AND METHODS

A total of 14 epoxy resin (Kemaboxy 150 Chemical Industries of Construction CIC-Egypt) blocks were fabricated with two implants (12 mm length and 4 mm width ROOTT company, Switzerland) mounted on each model simulating a case of missing mandibular first premolar and first molar teeth.[1,14] Epoxy resin material was selected thanks to its comparable modulus of elasticity to that of human bone (four Gpa).[14] A milling machine surveyor (Bredent, Germany) was used to hold both parallel implants in a specifically fabricated mold which was designed to hold accurately proportioned epoxy resin material till reaching its complete setting stage and bubble free models.[1,15,16] (**Figures 1&2)**

Figure (1): Milling machine surveyor holding two parallel implants during epoxy resin setting.

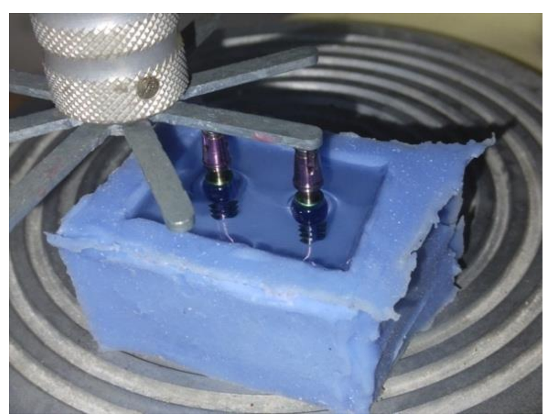

Figure (2): Epoxy resin slowly poured around each implant-abutment assembly.

After being tightly screwed to its corresponding titanium implant, each titanium abutment was sprayed to be scanned with a desktop 3D scanner (DS mizar, EG solutions, Italy) capturing all needed details.

The CAD software (Shera eco- mill) parameters were set for each group. For zirconia group, each framework was designed with 50 μm virtual cement space, 0.5 mm uniform thickness, (3x3 mm^2) connector area cross section (9mm^2) based on manufacturer's recommendations.[15,17] Frameworks were enlarged by about 20-25% to compensate for post sintering shrinkage. Frameworks were milled from pre-sintered zirconia blank (Aconia zirconia) using the 5-axis dry milling machine (Shera eco- mill 5x; Lemförde, Germany) followed by a sintering process for 10 hours in a high temperature furnace to reach full mechanical properties, while the PEEK group was designed with a (4x4mm^2) connector area cross section (16mm^2) ,0.7 mm uniform thickness and 50 μm virtual cement space. Frameworks were milled out of PEEK blanks (Bredent, Germany). Each framework connector area cross section was predetermined based on the minimal accepted dimension of each material.[15,17]

Each framework was checked for its dimensional accuracy using a dental caliper, and for its appropriate seating visually on its corresponding titanium abutment.

A total of 14 frameworks were divided into two equal groups (n=7) based on their materials of fabrication. All specimens were subjected before any testing to 5000 thermocyles (equal to 4-5 years of clinical service) in a thermocycler (Robota automated thermal cycle, BILGE, Turkey) to simulate intra-oral temperature fluctuations as aging highly affects the strength of each material, thus it may affect fracture resistance values. The low-temperature point was set at 5°C while the high temperature point reached 55 °C with a 10 sec lag time.[13]

Regarding fracture resistance testing, all specimens were individually subjected to a three-point bending test (testing materials stress/strain response) by a computer controlled universal testing machine. The machine was set at a constant cross head speed of 0.5 mm/min with a load cell of 5 kN and data were recorded using computer software. Each framework was secured to the lower fixed compartment of testing machine while axial compressive load from a load applicator attached to the upper movable compartment was directed to the center of pontic's occlusal surface. 0.5 mm thick teflon layer (10x10 mm length and width) was positioned between the pontic and the load applicator tip to avoid fracture from initial point of contact and ensure a homogeneous load distribution[15,18,19] **(Figure 3).**

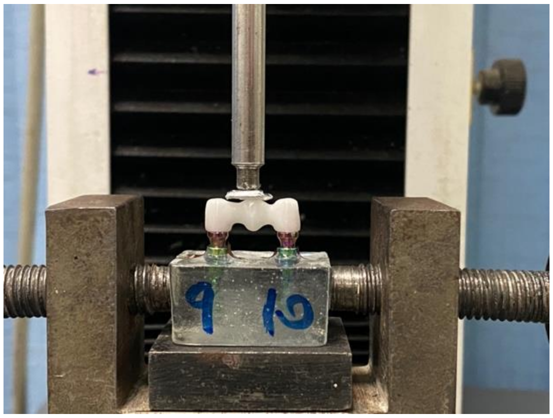

Figure (3): Load applicator tip directed to the pontic occlusal surface.

Applied load was gradually increasing till catastrophic failure was visually detected.

Failure was defined by a sharp drop in the loading curve. The compressive load that led to fracture was recorded for each framework in Newtons (N).

All retrieved fragments were collected, and failed specimens were examined to assess mode of failure using a digital microscope.[15]

RESULTS

Numerical data were explored for normality by checking data distribution and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Fracture resistance data showed normal (parametric) distribution. Data were presented as mean, standard deviation (SD), median and range values. For parametric data, Student's t-test was used to compare between the two groups. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp. Statistics showed that there was no statistically significant difference between the two groups (*P*-value = 0.441, Effect size = 0.426) as shown in **Table (1)** and **Figure (4)**.

Table (1): represents the mean, standard deviation (SD) values and results of Student's t-test for comparison between fracture resistance (N) of the two groups.

Zirconia		PEEK		*P*-value	Effect size *(d)*
Mean	SD	Mean	SD		
979.2	102.6	920	167.5	0.441	0.426

**: Significant at P ≤ 0.05.*

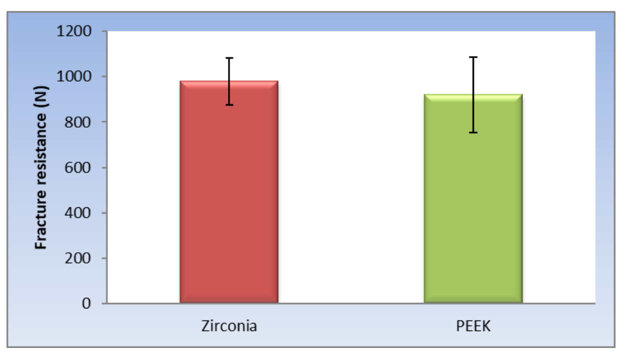

Figure (4): Bar chart representing mean and standard deviation values for fracture resistance in the two groups.

Regarding mode of failure, there was a statistically significant difference between failure modes of both groups (*P*-value = 0.001, Effect size = 1) as shown in **Table (2)**. All Zirconia frameworks showed catastrophic failure while all PEEK group showed plastic deformation **(Figures 5 & 6).**

Table (2): Frequencies (n), percentages (%) and results of Fisher's Exact test for comparison between failure modes of the two groups.

Failure mode	Zirconia		PEEK		*P*-value	Effect size *(v)*
	n	%	n	%		
Catastrophic	7	100	0	0	0.001*	1
Plastic deformation	0	0	7	100		

**: Significant at P ≤ 0.05.*

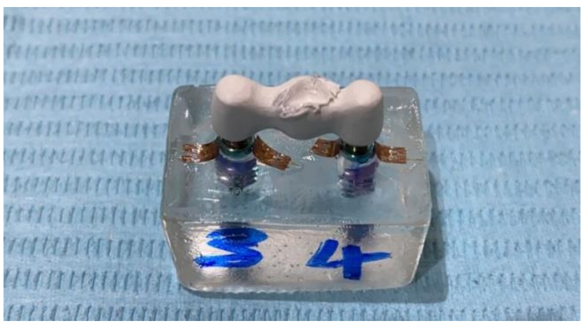

Figure (5): PEEK frameworks ductile plastic deformation upon load application.

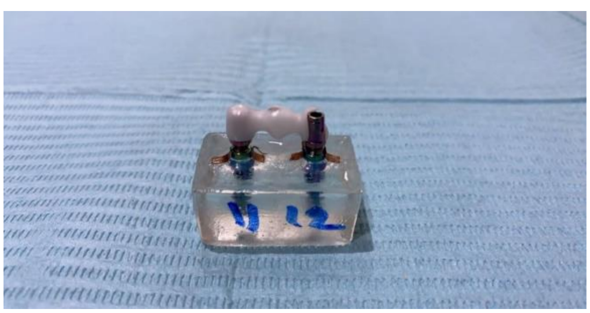

Figure (6): zirconia framework showing a catastrophic failure.

The fracture pattern was different for each material, the PEEK group showed a ductile type of failure starting at the gingival surface of connectors in all frameworks, while in the zirconia group the fracture mainly occurred at the loading point through one or both connectors. The fracture initiated at the connectors cervical area and spread diagonally toward the pontic's occlusal surface, while in PEEK, the cracks began in the upper zone of the connectors in all frameworks. Plastic deformation was detected without total fracture.

DISCUSSION

The success of a fixed dental restoration depends mainly on three factors: biomechanical factor such as wear resistance and fracture resistance, marginal fit, and esthetics.[10] According to the obtained results the null hypothesis of the present study was accepted. Selection of a material for implant supported superstructure is a crucial issue since it has a great impact on how stresses will transfer to the whole system affecting by this long-term clinical success and degree of implant-prosthesis stability. During function, any generated forces can be transferred to each prosthetic component as the implant itself, bone-implant interface and implant-abutment connection.[1] Zirconia restorations gained great reputation thanks to their exceptionally superior reported mechanical properties, even surpassing silica containing ceramics with excellent biocompatibility, reasonable esthetics, great stability.[5]

Monolithic zirconia restorations were introduced to overcome veneer chipping commonly encountered with bilayered restorations, especially in posterior area. Moreover, the excessively high hardness of monolithic zirconia (1200 VHN) restorations reported severe wear to the antagonist enamel and even to the milling tools during milling process. Low-temperature degradation (LTD) phenomenon with lack of etchability since it does not contain a glass phase are causes to search for new alternatives. Zirconia reported high stiffness and hardness; it has a great impact when zirconia is selected to fabricate an implant supported restoration. For such drawbacks, recent approaches are introduced to act as an alternative for zirconia implant supported superstructure.[16,20,21]

PEEK, a quite new polymer in the field of prosthodontics, was introduced for its shock absorbing property and its (4-4.8 Gpa) modulus of elasticity which is much more matching to modulus of elasticity of human teeth (15-83 Gpa).[22] When compared to zirconia, PEEK has a lower cost with comparable mechanical properties, and easier repairability within the mouth. Such advantages make PEEK material an attractive and even competitive candidate with zirconia for FPDs fabrication. PEEK cushioning effect is considered a great advantage specially if used for implant supported restorations fabrication, providing a uniform stresses transfer to the supporting bone and its frameworks can even protect abutment teeth from fracture incidences via stress absorption mechanism.[10]

Bio-HPP is considered the only material reaching the optimum balance between elasticity and rigidity.[9,23] (0.3 to 0.5 μm) grain size added constant homogeneity which is important for the material properties and leads to a constant quality.[24] Bio-HPP has been approved as a Class II medical device that can reduces the chance of any artifacts on magnetic resonance imaging due to its radiolucent. When comparing PEEK to zirconia, PEEK requires less fabrication time.[10]

In the present study, implant supported frameworks were fabricated via CAD/CAM by milling from PEEK and zirconia blanks. The advantage behind selecting milling protocol is that the desired geometry can be controlled by a computer software, and that it can create complex geometries with high degree of fit.[25,26]

In this study, implants were held during epoxy resin setting by using a surveyor for parallelism and to control both axial and vertical orientation of each implant.[1,17] Implants were also aligned in a straight line configuration for a favorable biomechanical outcome achieved when falling load direction coincides with the vertical axis of the implant.[27] Selection of epoxy resin was made to simulate bony matrix mechanical properties (modulus of elasticity reaching 3000 MPa).[14,17,19,28]

A 3D scanner was chosen to scan all details related to implant-abutment assembly since it offers great degree of precision and trueness eliminating any chance for laboratory imperfections. Frameworks virtual design parameters were selected in accordance with ***Rodríguez, et al***.[29] , ***Elshahawy, et al***.[17] and ***Alkharrat, et al.***[6] Zirconia frameworks connector area cross section was (3X3) mm^2, as recommended by several authors.[19,30]

Fracture strength, stress distribution and fracture pattern are three essential elements that may affect fixed partial dentures success.[10] This study evaluated the fracture resistance of posterior three-unit implant-supported frameworks constructed from zirconia and PEEK.[1]

Regarding fracture resistance readings recorded from each group, there was no statistically significant difference between both groups. The zirconia frameworks showed a mean fracture resistance of (979.2N) while the PEEK group showed a mean fracture resistance of (920N). These results came in agreement with other in vitro studies for zirconia frameworks that demonstrated a fracture resistance ranging from 900N to 1200N.[31] The load-bearing capacity of posterior four-units fixed partial dentures (FPDs) was investigated by ***Kohorst P* et al.**[32] and showed a mean value of (1263 N). ***Stawarczyck, et al***.[33] reported fracture strength of 1383N for uncemented three-unit milled PEEK FPDs. PEEK frameworks reported fracture resistance that could be attributed to the selected size of connector ($16mm^2$) which plays a major role in fracture resistance.[10]

PEEK three-units frameworks reported fracture resistance can be explained by multiple factors such as PEEK semi crystallinity with a degree of ductility, and it can accommodate a wide range of plastic deformation. This crystallinity enhances its hardness. PEEK CAD/CAM blanks fabrication under optimal conditions led to minimal chances for any porosities within the structure thus, to improved mechanical properties. PEEK frameworks were not subjected to a sintering high temperature and consequently possible contraction.[17]

The study results regarding fracture resistance are slightly lower than those obtained by other authors yet within the acceptable range and still higher than values reported for lithium disilicate glass ceramic (900N)[34]. Parafunctional forces can reach up to 800 N and this limit should be taken as a safe margin to ensure fracture resistance of selected material. In the present study, both groups recorded fracture resistance exceeding 900 N, thus, can withstand maximum chewing loads.[15]

Deviations in reported fracture resistance values in this study from what was reported in literature may be explained by difference in loading conditions, different connector area diameter, selection of implant abutment material or even cementation procedure.[1,33,35]

CONCLUSION

Within the limitation of this in-vitro study, the following were concluded:

1. PEEK can be considered a promising alternative to zirconia implant supported restorations with its mechanical properties and shock absorbing capability.

2. Both PEEK and zirconia can withstand chewing forces.

FUNDING: This research received no external funding.

CONFLICT OF INTEREST: The authors declare no conflict of interest.

REFERENCES

1. Nazari V, Ghodsi S, Alikhasi M, Sahebi M, Shamshiri AR. Fracture strength of three-unit implant supported fixed partial dentures with excessive crown height fabricated from different materials. J Dent. 2016;13(6):400–6.
2. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. J Prosthodont Res. 2016;60(1):12–9.
3. Rubo JH, Capello Souza EA. Finite-element analysis of stress on dental implant prosthesis. Clin Implant Dent Relat Res. 2010;12(2):105–13.
4. Barbosa M, Adelino V, Perez L, Carolina A, Gonçalves W. The role of superstructure material on the stress distribution in mandibular full-arch implant-supported fixed dentures. Mater Sci Eng c Mater Biol App. 2014;35:92–9.
5. Takata H, Komine F, Honda J, Blatz MB, Matsumura H. An in vitro evaluation of fracture load of implant-supported zirconia-based prostheses fabricated with different veneer materials. Clin Oral

Implants Res. 2018;29(4):396–403.

6. Alkharrat AR, Schmitter M, Rues S, Rammelsberg P. Fracture behavior of all-ceramic, implant-supported, and tooth–implant-supported fixed dental prostheses. Clin oral investing. 2018 ;22(4):1663-73.
7. Park CJ, Phark JH, Chee WW. Evaluation of fracture resistance of varying thicknesses of zirconia around implant abutment cylinders. J oral implantol. 2017;43(5):328–32.
8. Bechir ES, Bechir A, Gioga C, Manu R, Burcea A. The Advantages of BioHPP Polymer as Superstructure Material in Oral Implantology. JMSA. 2016;53(3):394–8.
9. Attia MA, Shokry TE, Abdel-Aziz M. Effect of different surface treatments on the bond strength of milled polyetheretherketone posts. JPD. 2022;127(6):866–74.
10. Wang B, Huang M, Dang P, Xie J, Zhang X, Yan X. PEEK in Fixed Dental Prostheses: Application and Adhesion Improvement. Polym J. 2022;14(12):1–19.
11. Kumar R V, Jain V, Prakash P, Uday Shankar V. Role of PEEK biomaterial in prosthodontics: A literature review. APRD. 2019;5(3):63–7.
12. Stawarczyk B, Eichberger M, Uhrenbacher J, Wimmer T, Edelhoff D, Schmidlin PR. Three-unit reinforced polyetheretherketone composite FDPs: influence of fabrication method on load-bearing capacity and failure types. Dent Mater J. 2015;34(1):7-12
13. Morresi AL, D'Amario M, Capogreco M, Gatto R, Marzo G, D'Arcangelo C. Thermal cycling for restorative materials: Does a standardized protocol exist in laboratory testing? A literature review. J Mech Behav Biomed Mater. 2014;29(September):295–308.
14. Kheiralla LS, Younis JF. Peri-implant biomechanical responses to standard, short-wide, and mini implants supporting single crowns under axial and off-axial loading (an in vitro study). J Oral Implantol. 2014;40(1):42–52.
15. Rodríguez V, Tobar C, López-Suárez C, Peláez J, Suárez MJ. Fracture load of metal, zirconia and polyetheretherketone posterior cad-cam milled fixed partial denture frameworks. Materials. 2021;14(4):1–12.
16. Mohamed HA, Alansary H, Kheirallah L. Retention Strength of Polyetheretherketone crowns Vs. Zirconia crowns restoring molar teeth: An in vitro study. EKB. 2021;2(1):1–13.

17. Hossam M, Elshahawy W, Masoud G. Evaluation of marginal adaptation and fracture resistance of Bio Hpp and Zirconia. EDJ. 2019 64(3):1489-1501
18. Emam M, El-Etreby A, Younis JF. Fracture resistance and strain analysis of zirconia copings with vertical knife edge and three horizontal finish line designs; chamfer, deep chamfer and shoulder with two cementation techniques. Braz Dent Sci. 2021;24(4):417-24
19. López-Suárez C, Castillo-Oyagüe R, Rodríguez-Alonso V, Lynch CD, Suárez-García MJ. Fracture load of metal-ceramic, monolithic, and bi-layered zirconia-based posterior fixed dental prostheses after thermo-mechanical cycling. J Dent. 2018;73:97–104.
20. Özkurt-Kayahan Z. Monolithic Zirconia: A review of the literature. biomedres J. 2016;27(4):1427–36.
21. Özkurt Z, Kazazoĝlu E. Clinical success of zirconia in dental applications. J of Pros. 2010;19(1):64–8.
22. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biom J. 2007;28(32):4845–69.
23. Reda R, Zanza A, Galli M, de Biase A, Testarelli L, di Nardo D. Applications and clinical behavior of biohpp in prosthetic dentistry: A short review. J.Compos.Sci. 2022;6(3):1-10.
24. Nabhan M. Effect of different fixed detachable implant supported prosthesis materials on the stresses induced on the supporting structures. Egypt Dent J. 2019;65(1):445–52.
25. Kim MJ, Choi YJ, Kim SK, Heo SJ, Koak JY. Marginal accuracy and internal fit of 3-D printing laser-sintered Co-Cr alloy copings. Materials. 2017;10(1):1–13.
26. Abdulsamee N. PEEK Biomaterial use for chairside cad/cam dental restorations: Bridging the gap to future. J Dental Sci. 2021;6(2):62-8.
27. Bavbek AB, Doğan A, Çehreli MC. Biomechanics of implant-tooth supported prostheses: Effects of mesiodistal implant angulation and mode of prosthesis connection. J Appl Biomater and Biomech. 2011;9(2):118–26.
28. Attia M, Amr H. Effect of different restorative crowns on fracture resistance and stress distribution in single implants; An In-Vitro study. Egypt Dent J. 2018;64(4):3813–22.
29. Rodríguez V, Castillo-Oyagüe R, López-Suárez C, Gonzalo E, Peláez J, Suárez-García MJ. Fracture load before and after veneering zirconia posterior fixed dental prostheses. J Pros. 2016;25(7):550–6.

30. Lopez-Suarez C, Tobar C, Sola-Ruiz MF, Pelaez J, Suarez MJ. Effect of thermomechanical and static loading on the load to fracture of metal-ceramic, monolithic, and veneered zirconia posterior fixed partial dentures. J of Pros. 2019;28(2):171–8.
31. Raigrodski AJ. Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature. J Prost Dent. 2004;92(6):557–62.
32. Kohorst P, Herzog TJ, Borchers L, Stiesch-Scholz M. Load-bearing capacity of all-ceramic posterior four-unit fixed partial dentures with different zirconia frameworks. Eur J Oral Sci. 2007;115(2):161–6.
33. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Polyetheretherketone - A suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater. 2013;101(7):1209–16.
34. Kolbeck C. Fracture force of tooth – tooth- and fixed partial dentures using titanium vs. customized zirconia implant abutments. Clin Oral Implants Res. 2008;1049–53.
35. Zaghloul HH, Younis JF. Marginal fit of implant-supported all-ceramic zirconia frameworks. J Oral Implantol. 2013;39(4):417–24.