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Distal cantilever length comparison in esthetic material for hybrid implant prosthesis: an in vitro study.

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Cover Page Footnote

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ORIGINAL ARTICLE / ARTICLE ORIGINAL

***Removable Prosthodontics** / Prothese Amovible*

DISTAL CANTILEVER LENGTH COMPARISON IN ESTHETIC MATERIAL FOR HYBRID IMPLANT PROSTHESIS: AN IN VITRO STUDY.

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Objective: the assessment of distal cantilever length in implant supported prothesis (Hybrid prosthesis) by comparing the load to fracture in two different esthetic framework materials (Zirconia and Polyetheretherketone (PEEK)) with two different cantilevers loading distances (10mm, 15mm).

Material and methods: 20 frameworks were fabricated and divided into 4 groups (n=5): according to the material type, Peek, zirconia, and according to the cantilever loading distance (10), or (15) mm and a load-to-fracture test was used until complete fracture of specimens occurs.

Results: The effect of material type and cantilever loading distance were statistically significant for the mean load-to-fracture values ($P< 0.05$). The Zirconia group failed at higher fracture loads (817 N) than the Peek one (651 N). Frameworks with 10 mm cantilever loading distance failed at higher fracture loads than specimens with 15 mm.

Conclusion: Peek is a suitable material for hybrid implant prosthesis(with distal cantilever in specific situations, and for zirconia   the success chances are higher in these types of prosthesis when the distal cantilever length is kept at its minimal value (10mm).

Keywords: Biomedical dental materials, zirconia, PEEK, cantilever, fracture load.

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Conflicts of interest:
The authors declare no conflicts of interest.

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COMPARAISON DE LA LONGUEUR DE L'EXTENSION DISTALE AU NIVEAU DES PROTHÈSES IMPLANTAIRES HYBRIDES RÉALISÉES AVEC DES MATÉRIAUX ESTHÉTIQUES: UNE ÉTUDE IN VITRO.

Objectif: l'évaluation de la longueur de extension distale dans l'infrastructure supportée par l'implant en comparer la charge des fractures et la résistance à la compression dans deux matériaux d'infrastructures esthétiques différents (Zircone et Peek), avec deux distances différentes de compression (10 mm, 15 mm). au niveau de l''extension distale.

Matériel et méthodes: 20 infrastructures ont été fabriquées et divisées en 4 groupes (n = 5): selon le type de matériau Peek, Zirconia et selon la longueur de l'extension (10) ou (15) mm, un test de compression au niveau de l'extension a été réalisé jusqu'à la fracture complète des échantillons.

Résultats: L'effet du type de matériau et de la distance de chargement de l'extension était statistiquement significatif pour les valeurs moyennes de la charge à la fracture (P <0,05). Le groupe de zircone a échoué à des charges de fracture plus élevées (817 N) que le groupe Peek (651 N). Les infrastructures avec une étendu d'extension de 10 mm se sont fracturées à des charges plus élevées que les échantillons de 15 mm.

Conclusion: Selon les résultats de cette étude on peut conclure que le Peek est un matériau approprié pour la reconstruction avec des Prothèse implantaire hybride) dans des situations bien spécifiques, tandis que pour la zircone on a remarqué que le taux de réussite est plus élevé lorsque la longueur distale du infrastructure est maintenue à une valeur minimale (10 mm).

Mots clés: Matériaux dentaires biomédicaux, zircone, PEEK, extension distale, charge de fracture.

Introduction

The increase in demand for metal-free implant-supported prosthesis led to the development of new esthetic and biocompatible dental materials used as frameworks. The All-on-four® implant-supported complete denture framework can be fabricated from a variety of materials. Traditionally framework material was cast from noble metal (gold) or base metal alloys (i.e Chromium-cobalt) veneered with heat-cured acrylic resin []. The advent of Computer Assisted Design (CAD) and Computer Assisted Milling (CAM) allowed milling of a substructure free from defects and distortions, passively fitting on the implant platform. This technological advancement also allowed for the fabrication of more complex substructures to provide support for stronger materials such as zirconia []. Zirconia is an aesthetic alternative to metal for implant-supported frameworks, one which offers biocompatibility, low bacterial surface adhesion, and good mechanical properties. On the other hand, zirconia is a rigid material with a high modulus of elasticity (210 GPa), which is considered a disadvantage in the masticatory shock absorbance of the prosthesis []. Also fully customized zirconia abutments showed a high wear at the implant – abutment interface. It is interesting to note that it is the titanium implant that showed higher wear at the implant interface when connected to a one-piece zirconia abutment compared to a titanium abutment [].

Recently Polyetheretherketone (PEEK) frameworks applied to the All-on-four® concepts have also been reported [3]. This material enjoys similar strength to that of the dentin and cortical bone [], and it has excellent biological compatibility []. In addition, it is compatible with aesthetic veneering materials With a modulus of elasticity of 4 GPa, its elasticity is similar to the bone, and it has the ability to reduce stresses transferred to the abutments [3]. A high modulus of elasticity could cause an overloading of the implant; hence, the transfer of forces to the bone-implant interface is limited in the case of PEEK framework given that it has a low modulus of elasticity [4]. Few studies have been reported to evaluate the performance of the PEEK frameworks for the rehabilitation of the edentulous patient using the All-on-four® concept, especially the behavior of this material in distal cantilevers that are essential components of an All-on-four® restoration to preserve decent functional capabilities of the patient.

Cantilever's length appears to be an important element in designing and fabricating full-arch prosthesis. Moreover, the height and width of the cantilever are crucial in minimizing the amount of deformation of the prosthesis []. Today, a large number of materials are available to produce a prosthesis infrastructure. It is recommended that metallic alloys exhibit high tensile strength (>300 MPa) and elastic modulus (>80,000 MPa) sufficient to prevent deformations and cantilevers fractures []. Still, guidelines for designing or implementing tooth-colored material frameworks with distal cantilevered segments have not been established yet []. PEEK has an elastic modulus that is close to human bone, suggesting homogeneous stress distribution to surrounding tissues. Its radiographic radiolucency and low density (1.32 g/cm3) make it suitable for medical applications []. PEEK is an inert material with high compatibility to the surrounding tissues and do not reveal any toxicity. Therefore, it is ideal for patients allergic to titanium and other metals. PEEK isn't like metal; its color is beige with a touch of grey and has a more aesthetic appearance than the metal [].

Limited studies have evaluated the load to fracture of cantilevers in implant complete fixed denture (ICFD) or hybrid implant prosthesis frameworks. This in vitro study was designed to investigate the behavior of PEEK implant prosthetic frameworks and adds more information about the length of the distal cantilever, the design and dimensions of the framework. This study aims to assess PEEK distal cantilever reliability in implant supported infrastructure by comparing it to zirconia's resistance to load with two different cantilever loading distances (10mm, 15mm). As our study is clinically oriented, we have provided substructures of both materials (PEEK and Zirconia) with maximum possible dimensions specific to each material individually in order to better achieve the functional role of the prosthesis.

Materials and Methods

This in vitro study was performed on two exact custom-made epoxy resin models (M1 and M2), 20 mm wide, 20 mm high, and 50 mm long. Three pairs of Straumann tissue level analogs 4,1 ×12mm and the corresponding Variobase Ti-level for bridges abutments (Straumann RN synocta, Straumann Holding AG, Basel Switzerland) were seated in each model. Parallel vertical drilling was performed on two sites of the bloc for the two anterior implant analog locations, and a 30 degree tilted drilling was performed for the most distal implant analog. All the drilling sites were made 8mm apart. The three analogs were fixed in place with epoxy resin cement (Alteco Chemical Pte Ltd, Singapore) and the abutments were fitted in the analogs and tightly torqued as per the manufacturer's recommendations.

Twenty frameworks were milled and divided into 4 groups (n=5), according to material type (PEEK or zirconia) and to the cantilever loading distance (10 or 15 mm). The first epoxy test apparatus (M1) was scanned by the Arum 3D scanner (Arum Europe GmbH Frankfurt, Germany). 10 PEEK frameworks (CopraPeek Medium®, White Peak Dental System

Essen, Germany), were milled using Arum 5X-200 milling unit (Arum Europe GmbH Frankfurt, Germany). In addition, the second epoxy test apparatus (M2) was scanned with the Arum 3D scanner and 10 zirconia frameworks were milled using (Copran Zri®, White Peak Dental System Essen, Germany). All the zirconia frameworks were sintered according to the manufacturer's instructions in a sintering furnace (ARUM HTS-2, Arum Europe GmbH Frankfurt, Germany) (Fig.1)

The frameworks were designed using Exocad software (Exocad GmbH, Darmstadt, Germany), and the cross-section of the frameworks was a rectangular shape with a full length of 40 mm. Connector dimensions for PEEK frameworks were 6×6mm for between implants connectors and 8x6mm for the distal cantilever connector, and for the zirconia group they were 4×4mm and 6x4mm, respectively. Abutment wall thickness was 3mm for PEEK, and 2mm for zirconia. (Fig.2)

At the level of each cantilever. Two dimples of 2 mm in diameter and 0.5 in depth were created on the upper surface of each cantilever at 10 and 15 mm from the distal implant to facilitate the loading rod positioning. (Fig.3)

Finally, the Variobase abutments were cemented on each bar by resin cement (Variolink Esthetic dual-curing luting cement, Ivoclar Vivadent, Schaan, Liechtenstein). The frameworks were kept to rest for 24h before the loading experimentation to allow the complete harden of the resin cement.

Each framework was then mounted on the implant analogs, screwed and torqued at 35 Ncm with a manual torque wrench. Moreover, a mini stainless steel clamp was attached to each framework at the level of the first abutment to hold steady the whole apparatus together (framework and epoxy model), and avoid any disengagement of the cement during the load application.

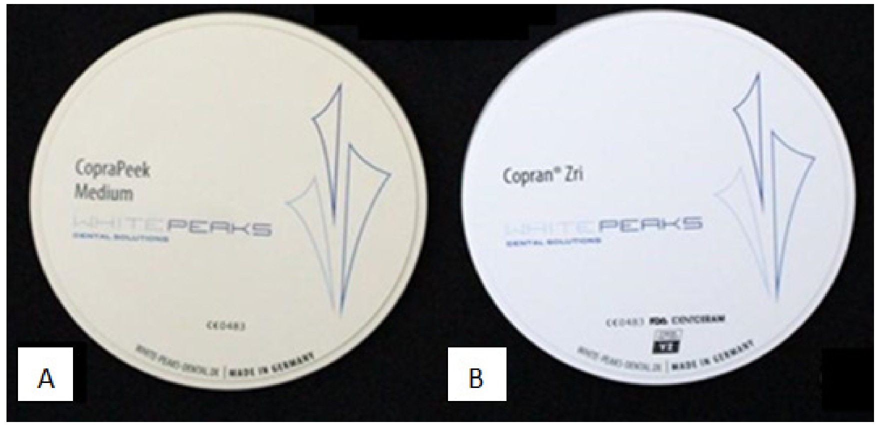

Fig. 1: PEEK, ZrO2 disks. A: Polyetheretherketone (PEEK) disks Whitepeaks Dental Solutions GmbH & Co. KG. B: ZrO2 (yttrium oxide-stabilized, tetragonal zirconia dioxide disks Whitepeaks. Dental Solutions GmbH & Co.)

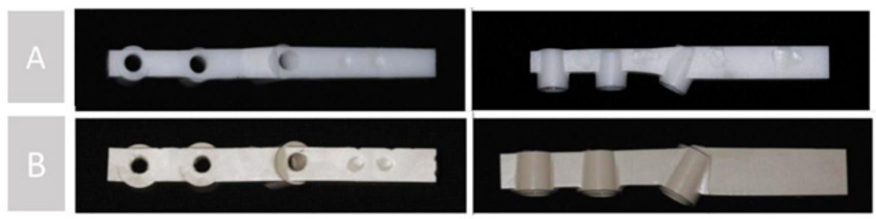

Fig. 2. Occlusal and lateral view of the frameworks: A: Zirconia framework with Dimensions: 4×4 mm2 for non-cantilever connectors, 6×4mm2 for Cantilever connector, and 2mm for Abutment wall thickness. B: Peek framework with dimensions: 6×6 mm2 for non-cantilever connectors, 8×6mm2 for Cantilever connector, and 3mm for Abutment wall thickness.

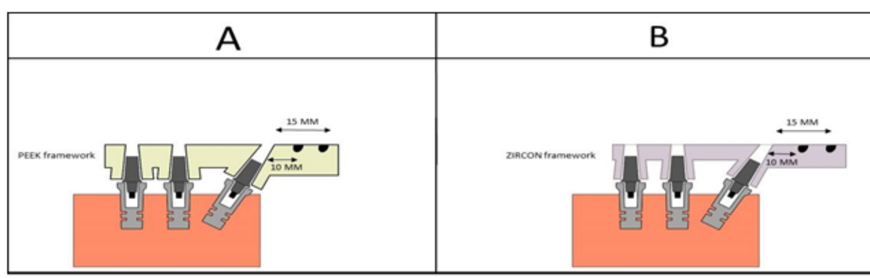

Fig. 3. A: cross section of first epoxy test apparatus with Peek which was tested at (10 or 15) mm cantilever length. B: cross section of second epoxy test apparatus with Zr which was tested at (10 or 15) mm cantilever length.

Testometric M350-10KN (Testometric Co Ltd, Rochdale, UK) was used to measure the load to fracture values of the frameworks. An axial load was performed at a crosshead speed of 2 mm/min until complete breakdown.

The traditional load-to-failure test was performed, which uses a static load that is increased incrementally with a 2 mm/min crosshead speed until the failure of the specimen. All specimens were loaded from 0 Newton (N) until the occurrence of the fracture. The load was applied on the dimples located at 10 mm or 15mm distance from the posterior implant. The load value at the cantilever's fracture was automatically recorded by the software.

For statistical analysis, two-way ANOVA and one-sample t test were used with a significance level of 5%. The software used was SPSS Windows version 18.0 (IBM, Armonk, New York, United States)

Results

Sample's Description

The sample contained 20 frameworks divided into two main groups according to Framework Material (Zirconium Group and PEEK Group). Each one of the main groups was divided into two subgroups according to Cantilever Loading Distance (10 mm Group, 15 mm Group).

Statistical Analysis:

Load to fracture (in newtons) was measured for each framework.

The results of the study are summarized in Table 1.

S. No	Zirconia: Cantilever (10) mm	Zirconia: Cantilever (15) mm	Peek: Cantilever (10) mm	Peek: Cantilever (15) mm
1	803	564.1	669.8	345.6
2	772.2	567.8	653.2	399.9
3	812.2	586.4	684	378.9
4	862.9	532.2	622.1	402.5
5	838	526.2	627	352.5

Table.1. Summary of Load-to-Fracture Test Values

The highest load-to-fracture values were found for the zirconia group with 817.66 N for 10 mm and 555.34 N for 15 mm cantilever loading distance, and the lowest values were found for the PEEK group with 651.16 N for 10 mm and 375.88 N for 15 mm cantilever length. (Fig.4&5)

Effects of Framework Material and Cantilever Loading Distance on load to fracture (in newtons) were studied. The statistical analysis result listed as follows:

- *Effect of Framework Material on load to fracture values according to cantilever loading distance (CLD) variable study*

Independent Samples T test was applied to know if there were significant differences in load to fracture values (in newtons) between Zirconia Group and PEEK Group according to cantilever loading distance variable.

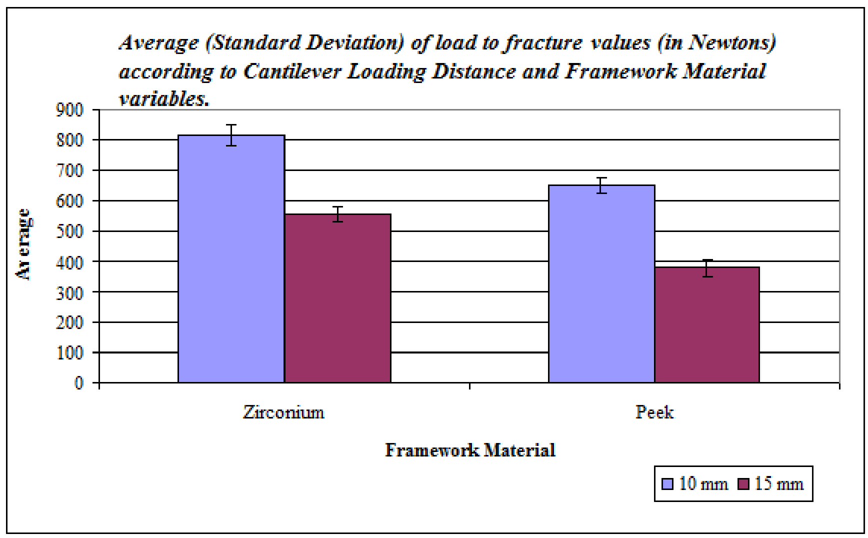

Figure 4: Average (Standard Deviation) of load to fracture values (in Newtons) according to Framework Material and Cantilever Loading Distance variables.

Independent Samples T test results:

The table below (table 4) shows that both P-values were much lower than 0.05, so we can conclude that there were significant differences in the load to fracture values (in newtons) Zirconia Group and PEEK Group whatever the Cantilever Loading Distance was the sample. Positive Algebraic sign of mean differences indicates that load to fracture values (in newtons) in Zir-

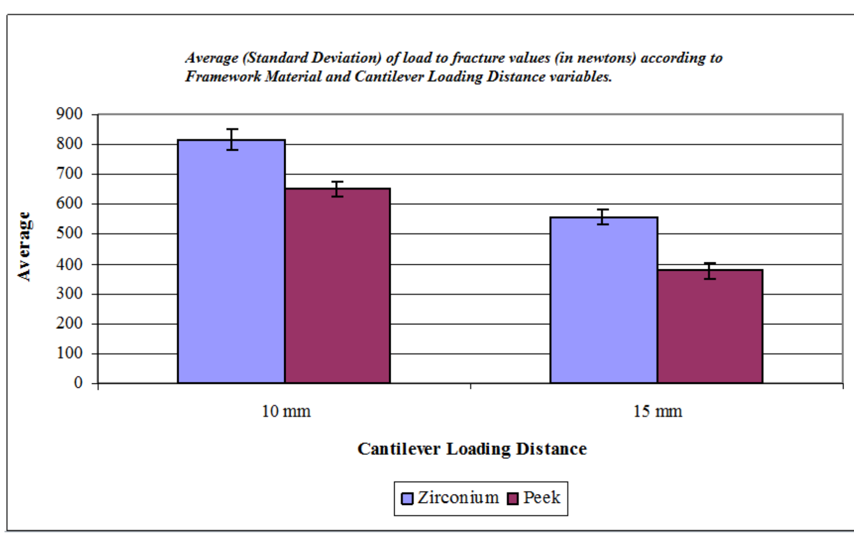

Figure 5: Average (Standard Deviation) of load to fracture values (in newtons) according to Cantilever Loading Distance and Framework Material variables.

conium Group were greater than those of PEEK Group whatever the cantilever loading distance was in the sample.

Studied Variable = load to fracture (in newtons)				
Cantilever Loading Distance	Mean Difference	t value	P-Value	Significant diff.
10 mm	166.50	19.54	0.000	YES
15 mm	179.46	16.34	0.000	YES

Table 4: Independent Samples T test results to know if there were significant differences in load to fracture values (in newtons) between Zirconium Group and Peek Group according to Cantilever Loading Distance variable.

- Effect of cantilever loading distance on load to fracture values according to framework material variable study

Independent Samples T test was applied to know if there were significant differences in load to fracture values (in newtons) between 10 mm Group and 15 mm Group according to framework material variable.

Independent Samples T test results:

The table below (table 6) shows that both P-values were lower than 0.05, so we can conclude that there were significant differences in the load to fracture values (in newtons) between 10 mm CLD Group and 15 mm CLD Group whatever the framework material was. Positive Algebraic sign of mean differences indicates that load to fracture values (in newtons) in 10 mm CLD Group were greater than those of 15 mm CLD Group whatever the framework material was in the sample.

Fracture Mode:

The failure mode for zirconia frameworks was complete fracture without plastic deformation, while for PEEK frameworks complete fracture happened after elastic deformation.

There was no damage or permanent bending in the variobase abutments, abutment screws, or analogs in all the frameworks.

The fracture locations had varied, for peek frameworks, all the fractures happened at the distal abutment level, while for the zirconia frameworks, the fractures happened in two different locations influenced by the cantilever loading distance; six of the zirconia frameworks fractured at the level of middle abutment while four of them fractured at distal abutment level. (Fig.6)

Discussion

In this study, the fracture resistance of the cantilever in All-on-four® frameworks with two different materials and different cantilever lengths was examined. The load to fractures was the highest for the Zirconia frameworks, and the lowest loads were sufficient to fracture the PEEK frameworks. It is also noted for all the categories the load to fracture was the highest for the shortest cantilever.

A bite force measurement of 541.4N in the elderly had been reported by Chong et al [] . Kogawa et al [] found the mean maximal bite force in control subjects to be 338 N. Moreover, di Rossi et al [] found that the muscular activity of the All-on-four® group was similar to that of the dentate group during clenching, non-habitual chewing, and habitual chewing. It follows that if All-on-four® prosthesis compensates enough to gain the levels of bite values for dentate subjects over 60 years old, then PEEK framework for hybrid prosthesis with a 15 mm cantilever should be discarded, because it's high risk of fracture. Unilateral measurement of maximum bite force in the molar region aver-

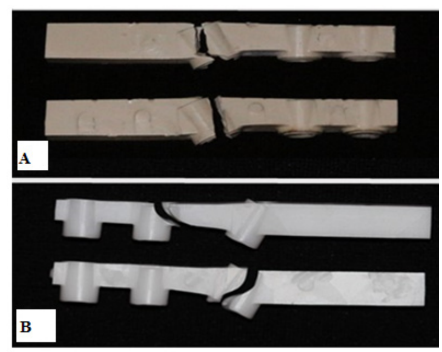

Fig.6. Fracture Mode: A- B- for Peek and Zirconia respectively framework's complete fracture.

ages between 300 and 600 Newtons (N) in healthy adults with natural teeth. [] . However according to Waltimo et Al [] fracture strength reported for PEEK prostheses was higher than the physiological maximum posterior masticatory of 870 N. Both esthetics materials namely Zirconia and PEEK used in this study scored values within those ranges mentioned above which are enough to resist masticatory forces in just the 10mm cantilever group.

One of the critical factors for the long-term success of the fixed implant-supported prosthesis is the framework design []. The design depends primarily on the geometry and characteristics of the material []. Malo et al, and Jivraj [3,] had similar recommendations for PEEK bars: The height should have a minimum of 4 mm. Posterior wall thick-

Studied Variable = load to fracture (in newtons)				
Framework Material	Mean Difference	t value	P-Value	Significant diff.?
Zirconium Group	262.32	13.681	0.000	YES
Peek Group	275.28	16.420	0.000	YES

Table 6 Independent Samples T test results to know if there were significant differences in load to fracture values (in newtons) between 10 mm Group and 15 mm Group according to Framework Material variable.

ness should be a minimum of 6 *mm* and anterior wall thickness, a minimum of 5 mm. The abutment wall thickness should be a minimum of 1 mm []. For tooth-supported zirconia-based restorations, the minimal recommended dimension of connectors is 4 x 4 mm; this was applied to the design of implant-supported frameworks, preserving 16 mm^2 of section area, at the level of connectors []. Sereno et al [], have evaluated the load to fracture of PEEK frameworks; their in vitro study was designed to investigate the behavior of a PEEK implant-supported prosthesis with a cantilever design in a five-year chewing simulation. The fracture values after 5 years of simulated chewing were 4393N for the fully anatomic PEEK denture and 2553 N for the PEEK framework with composite veneering.

Another in-vitro study evaluated the load to fracture of zirconia frameworks, De Fransco et al [] concluded that zirconia All-on-four® frameworks loaded at 10 mm cantilever length, and with 10 mm^2 cross sectional dimension using (Zenostar T manf) failed at 905 N. In comparison to the De Fransco study, the zirconia framework loaded at the same cantilever length and with 16 mm^2 cross section area using (Copran Zri®) failed at 817 N. So we had a lower load to fracture force even though the higher thickness, and this discrepancy can be explained by the concentration of the force at the end of the cantilever in this study in contrast to De Fransco 's study who interposed a silver foil of 1 mm thickness between the pressure gauge and the framework in order to better distribute the force on all the cantilever length *.*

Regarding the influence of cantilever length and connector dimension on the fracture force of CAD/CAM manufactured zirconia implant prosthesis frameworks, Chong et al []. compared the load-to-fracture of 3x5 mm, 3x4 mm connector dimension and 7- and 10-mm cantilever length frameworks. Specimens 10 mm of cantilever length and 3x5 mm connection area fractured at a mean load of 923.7 N and 1011.7 for 7 mm cantilever length, while specimens with a connection area 3x4 mm failed at 474.8 N and 700.9 N for 10 and 7 mm of cantilever length, respectively [17]. The authors suggested that cantilever in zirconia frameworks might be best limited to a single cantilever unit. Compared to the values 817 N reported in our experiment when we tested a 10 mm cantilever length of zirconia material with a cross-sectional area of the connector 4x6 mm, the reported mean load to fracture in the above study 923.7 N was higher for the same cantilever length and a smaller connector area (3x5 mm vs 4x6 mm) used in the previous study. This variation could be due to the difference in the framework designs, in this experiment the frameworks were cemented on the Variobase® abutments, while in the Chong et al. study, the frameworks were screwed directly into the implant analogues which may give them more strength and resistance to fracture. It was noted that the zirconia-implant interface weakest point was at the level of the internal connection. It is also clear that using a secondary metallic component helps improving fracture resistance of the abutment [] and that's why Variobase® abutment was used in our study and a metallic interface was cemented on the tested infrastructure.

Another in vitro study by Alshahrani [] also compared different specimens according to the cantilever length (7 mm, 10 mm, and 17 mm) and connector dimensions (6x6 mm, 6x8 mm, and 6x10 mm). The highest load-to-fracture value was found for the group with the highest occlusal-cervical dimension (10 mm) and the shortest cantilever length (7mm). The results from this study showed that increased vertical thickness at the connector level provided improved fracture resistance. This is in agreement with the results reported by Chong et al [23]. The values found *by Alshahrani et al study were by far higher than the results found in the present study in the group of the identical connector area and cantilever length dimensions this may be explained by the fact that Alshahrani et al. used plain rectangular zirconia rods without any form of abutment(i.e Variobase) in contract to the present study where zirconia framework were seated on variobase abutments and adversely it was noted that most of the fracture pattern were located around the Variobase abutments.*

Also, Nazari et al []. reported that the mean fracture strength of the PEEK restorations(1430N) was considerably lower than Zirconia ones, but were considerably higher than that of the reported physiological maximum posterior masticatory force of 880N. They concluded that PEEK restorations fabricated in excessive crown height space can potentially withstand physiological occlusal forces. One of the main shortcomings of PEEK restorations is their low bonding to the veneering materials. Several studies showed adhesive failures or crown popping of PEEK frameworks; others showed different bonding techniques to avoid failures such as sandblasting and laser treatment, among others [,,]. This fact can be explained by the deformation of the PEEK frameworks under load before the complete fracture as observed during the experimental procedures in this study where the PEEK frameworks bended under load before complete fracture. The frequent disengagement of the veneering material from the framework can be explained by this bending phenomenon*.*

Due to its low elastic modulus PEEK provides a cushioning effect on occlusal forces. When it is combined with low elastic modulus materials such as polymethyl methacrylate (PMMA) or composite resin, it will further reduce occlusal forces to the restoration and the opposing dentition []. Therefore, the use of PEEK can be advantageous for implant-supported prosthesis where there is no proprioception on implant interface. Screw loosening and veneer complications are reduced to minimum. On the other hand, the use of rigid frameworks fabricated by metal or zirconia could lead to plastic deformation of the implant shoulder and screw fractures [].

PEEK frameworks can be restored with ceramics- the Toronto bridge style- such as zirconia and lithium disilicate crowns and composite veneers. The present study showed promising results, and according to the values of the load to fracture we can achieve reliable prosthetic solutions with PEEK by increasing to the maximum the volume of material in the posterior region to give all the chances for the prosthesis to withstand the masticatory forces. This observation may open new horizons for the monolithic multilayered All-on-four® PEEK restorations.

Limitations of this study

- The samples were not exposed to fatigue loading and thermocycling to imitate oral conditions.
- The forces applied are static and not dynamic; static axial loading cannot always simulate actual functional conditions.
- The PEEK and zirconia different infrastructures were not dimensionally standardized; these frameworks were milled according to the fabricant's recommendations with individually suitable dimensions for each material in order to withstand functional loads.

Finally, within the limitation of this study and according to the load-to-fracture values for the materials tested in this study, several points related to the clinical practice can be outlined:

1-PEEK frameworks can be used with reliable results for an All-on-four® prosthesis provided a distal cantilever length limited to 10 mm., particularly with cases with large prosthetic space and patients with low muscular forces (i.e, elderly, and female) or when the antagonist arch is a removable prosthesis.

2- Zirconia All-on-four® frameworks are recommended for cases with moderate prosthetic space and regardless to the antagonist arch with a distal cantilever length that does not exceed 10mm.

3- For both esthetic materials namely Zirconia and PEEK the construction of All-on-4 prothesis with cantilever length greater than 10 mm is not recommended.

Conclusion

This study explored the cantilever feasibility in hybrid implant prothesis with two esthetic framework materials namely Zirconia and PEEK. A load-to-fracture test was conducted on two different framework materials (PEEK and zirconia) that were used for hybrid implant prosthesis with two different cantilever loading distances (15 mm or 10 mm). The highest load-to-fracture values (817.66 N) were found for the zirconia framework with 10mm cantilever length and the lowest load (375.88 N) was needed to fracture the PEEK frameworks with 15 mm of cantilever length. Frameworks with 10mm cantilever length showed the highest load-to-fracture values for both materials PEEK and zirconia. Short cantilevers (10 mm) can be safely used for Zirconia and PEEK hybrid prosthesis frameworks with reliable results under specific conditions for each material. However, further in vitro and clinical studies are needed to evaluate the long-term performance of these esthetic materials in hybrid implant prosthesis.

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