ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
December 2023 • Vol. 32

Comparative stress analysis of BioHPP and PEKK CAD/CAM frameworks in mandibular All-on-Four fixed-detachable prosthesis on its supporting implants

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Aim: The aim of this simulation study to evaluate stresses induced on supporting implants by different framework materials BioHPP and PEKK in mandibular implant supported fixed-detachable prosthesis following all-on-4 concept using strain gauge analysis.

Material and methods: For this study, 3D printed model simulating completely edentulous mandibular arch with4implants placed in all-on-4 configuration to support fixed-detachable prosthesis were constructed. According to framework material of screw-retained fixed-detachable prosthesis: Model I: framework made from Bio-High Performance Polyether (BioHPP) while Model II: framework made from Poly-ether-ketone-ketone (PEKK). Strain gauges were installed at mesial of central implants and distal to distal implants. Bilateral and unilateral load was applied starting from 0-60 N. Microstrains were recorded at each strain gauge with enough time elapsed between tests. The process was repeated 5times for each group, average strains were recorded and statistically analyzed.

Results: Individually results for both models showed unilateral loading induced more stresses compared to bilateral loading. Statistical significant higher microstrains were induced at distal of distal implants than mesial of central ones in both unilateral and bilateral loading. Comparing the two models although less stresses were detected in model II (PEKK framework) compared to model I (BioHPP framework) statistical analysis of data revealed significant difference at distal aspect of distal implants in both unilateral and bilateral loading.

Conclusion: Within limitation of this simulation study, using polyether-ketone-ketone (PEKK) for constructing the framework of prosthesis lead to favorable stress distribution and reduces stresses induced to supporting implants. Further clinical studies are required to confirm this finding.

Key words: Bio-High Performance Polyether (BioHPP), Polyether-ketone-ketone (PEKK), fixed-detachable, All-on-4, stress analysis.

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Introduction

In edentulous patients asking for an implant-supported prosthesis, it may not be practical to use multiple implants in many cases because of the nearby anatomical structures and the quality and quantity of remaining bone and the expenses.[1] In two retrospective trial studies, Maló et al.[2,3] introduced a planning protocol aimed at the rehabilitation of the completely edentulous mandible and maxilla by four implants (Nobel Biocare, Kloten, Switzerland) to overcome the anatomical restrictions in these cases that make it challenging to treat deprived of the use of more complicated techniques.

"All-on-four" treatment concept was established to use the remaining available bone in the atrophic ridge to the maximum, permitting immediate function and avoiding regenerative techniques that elevate the treatment costs and patient satisfaction, in addition to the inherent complications of these procedures.[4] In this protocol four implants are placed in the anterior region of completely edentulous arch to support an immediately loaded provisional, fixed prosthesis. Two vertically placed anterior implants, whereas the posterior ones are placed distally angled to maximize the length of used implants and avoid the critical anatomical structures nearby, minimize the length of cantilever and to permit the use of up to 12 teeth in the prosthesis, thus enhancing the masticatory efficiency.[2]

It is a safe and efficient surgical and prosthetic protocol and documented as a viable long-term treatment protocol up to ten years in function.[4,5] The objective of all-on-4 design is to construct full arch fixed prosthesis using fewer implants placed anteriorly when implants cannot be located posteriorly owing to the anatomic limitations. In accordance with Misch[6] opinion that mandibular motions distal to the mental foramen in fixed prosthesis affect the prognosis of implants negatively and that when implants are placed between the mental foramina in full arch fixed restorations, less bending forces happen in the mandible, thus in all-on-four technique, implants are located interforamina. Moreover, this design minimizes or eliminates the posterior cantilever and its complications.[7]

In its designs, screw-retained implant-assisted full-arch prosthesis is preferred. It has been emphasized that it is biomechanically adequate owing to can be used in short abutment length, easy removal of the prosthesis for prosthetic hygiene and in case there is a problem with the abutment and/or the implants thus removed at the clinician's control.[7,8]

Using appropriate materials while applying the "All-on-4" concept in the edentulous patients greatly influence the long-term success of the dental implants.[9] Some of the researchers have assumed that framework material affects the amount of stresses transmitted to the adjacent components.[10-12] while others affirmed that its effect insignificant.[13]

In all-on-four implant-assisted prostheses, prosthetic materials used are a principal factor that affects stress/ strains detected in implants and peri-implant bone. In this regard, metal-reinforced hybrid fixed prosthesis, metal-reinforced ceramic restorations and zirconia-reinforced ceramic fixed prosthesis were used. A metal substructure was suggested because of its rigid structure, also full-acrylic resin prosthesis was suggested for its shock absorbing occlusal surface that led to reduction in the stresses transmitted to the bone-implant interface and documented to have long survival rate.[14,15]

At first, the prosthesis used to be constructed above a fused metallic framework. More recently, using polymers has been suggested for this purpose.[16] Polymer's industry is in continuous development and progress with important applications in general and dental medicine in different technological alternatives for rehabilitation of the oral cavity.[17]

Currently investigations are conducted for new capabilities to use PEEKs in Prosthodontics. They can be combined with metal alloys for fabrication of alternative fixed restorations.[18, 19]

High Performance Polymer (BioHPP) is a high-technology thermoplastic polymer based on polyether-ether-ketone (PEEK) polymer, it was applied for years in surgical procedures owing to its excellent stability, it has low plaque affinity and its optimal polishing properties, BioHPP can be used for accurate fabrication of prosthetic superstructure on implants. The presence of 20% ceramic filler leads to its strength and improved its mechanical properties. Its constant homogeneity is established because of its tiny grain size (0.3-0.5 µm), and this is important for the material properties and establishes the foundation for persistent quality.[18,20]

BioHPP is nearly elastic as bone due to its modulus of elasticity 4 GPa, which is very important property in implant prosthetics as twisting forces may take place especially in cases with larger implant frameworks. This helps dissipate any stresses, balance out bone-related torsion and reduce the risk of fracture.[21]

Conventionally, denture frameworks are made from Chrome-Cobalt. BioHPP can be its practical alternative as it is lighter, does not produce galvanic elements (corrosion) if comes nearby other metals in the oral cavity thus it is suitable for patients allergic to metals due to its low reactivity toward other materials. Moreover, the white colour of BioHPP framework provides different esthetic approach when compared with conventional metal framework.[22]

Polyether-ketone-ketone (PEKK) is a novel methacrylate-free polymeric material that has attracted the investigators' attention because of its excellent properties that allowed it to be used in many applications.[20] BioHPP and PEKK are alterations of the main thermoplastic high performance polymer family, polyaryl-ether-ketone (PAEK).[23]

PEKK has better mechanical properties as higher compressive strength, the addition of titanium dioxide (TiO_2) and the second Ketone group increases rigidity with its wear resistance and hardness, excellent polishing ability and elastic modulus near to that of bone.[24] PEKK offers metal-free restorations and has excellent biocompatibility thus it is considered as substitute to metal and ceramics in restorations.[25]

PEKK has compressive strength near to bone and dentine shock absorption. Recently It became the material of choice in implant super-structures for the construction of the framework in full arch prosthesis owing to its light weight and that it is compatible with variable veneering materials, also used for construction of fixed arch bridgework abutments, bridges resin-based composite veneered substructures and in removable prosthesis as bars and telescopes beside it can be used in implant overdenture attachments.[23,26]

Among the advances in digital dentistry, computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have enabled the clinicians to use different material combinations with increased accuracy and gained popularity to be easier for the fabrication of modern restorative and prosthetic materials. Recently, the construction of PEKK prosthetic restorations used CAD/CAM technologies.[27,28]

The ability to digitally design and modifying the pontic morphology is one of the major advantages offered by using CAD/CAM technology. In addition, the stored dataset can be used for multiple millings with no need for new intra-oral impression thus provide easy replacement of fractured prosthesis or for trying of different aesthetic designs.[29]

Measuring the mechanics that arise in a system comprising the bone- implant site, the implant and its superstructure requires highly complex methods. Currently available two established conventional methods the first method is computer-based virtual finite element method (FEM) and the second adequate measurement method is using strain gauges that are used to detect surface deformations of dental prosthesis or peri-implant bone when subjected to stress. Strain gauges are used to clarify the biomechanical performance of implant-supported prosthesis mimicking variation of cases and designs thus can be used to assess their effect on the supporting implants.[30-32]

Although, numerous in-vivo and in vitro studies have been published evaluating the effect of different denture base materials on the implant supporting structures, detailed reports on the effect of PEKK are limited. This invitro study meant to assess and compare the strains induced to the supporting implants by BioHPP and PEKK framework manufactured using CAD/CAM in mandibular screw-retained prosthesis following All-in-four design. The null hypothesis of this study was that there would be no significant difference in the stresses transmitted by the frameworks BioHPP and PEKK to its supporting implants.

Materials and Methods

This in-vitro stress analysis study was done on 3D computer-generated cast model simulating a completely edentulous mandibular arch with four implants placed following all-on-4 concept to support fixed-detachable prosthesis. According to the framework material used for the construction of the screw-retained fixed-detachable prosthesis, the models were divided into two groups: Model I: Bio-High Performance Polyether (BioHPP) framework was used, while Model II: Polyether-ketone-ketone (PEKK) framework was used.

Construction of the 3D models:

A completely edentulous mandibular educational model was scanned via desktop scanner (Optical scanner, 3Shape Smart optics, Denmark). According to All-on-four configuration denoting the osteotomy sites, four implant beds were planned to receive standardized implants (Nobel Biocare) whose dimensions 3.7 mm diameter x11.5 mm length. The two central implant beds were designed to be vertically placed in the lateral- canine region while the two distal implants placed tilted with 30º angle in the premolar region located at equidistance from the midline.

One groove was designed at each implant bed for the future connection of the strain gauges, with a flat plane parallel to the long axis of the implants and separated by 1 mm at the mesial aspect of the central implants and at the distal aspect of the distal implants. Fig. (1A)

STL file was created, in which a 2 mm cut back of the ridge surface was performed for the addition of the mucosa-simulating material. A mucosal index was designed with 2 mm thickness and 2 mm offset with 4 tissue stops that were widely distributed on the ridge for creating a space for the mucosa simulator.

The STL files were sent directly to the additive manufacturing device (3d printer, Taiwan), that utilized a DLP chip to print the casts layer by layer utilizing the projection of an ultraviolet light to polymerize the layers till printed the entire cast. Photopolymer (ABS like resin grey, Taiwan) was used in the production of the printed model. Fig. (1B)

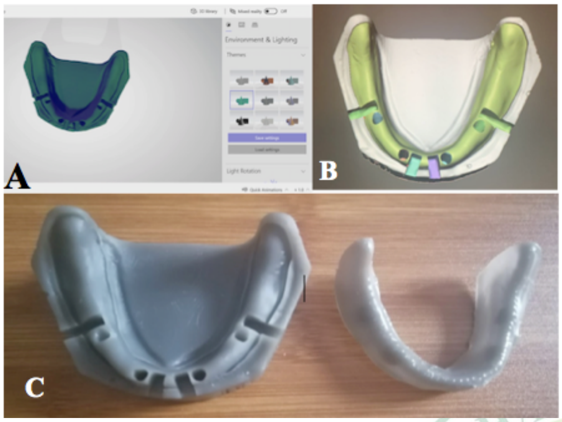

Fig. (1): A,B) STL view of the planned 3D model. C) 3D print of the planned mandibular model and the mucosal index

Preparation of the edentulous mandibular cast for prosthesis fabrication:

Four implants were inserted in their planned beds and auto-polymerized acrylic resin (Acrostone, Egypt) was applied to fix the implants to the cast. Then mucosa-simulating material (Gingisil, Silconic, Germany) was injected into the printed mucosal index that was pressed against the model until the stoppers touched the cast surface to ensure proper uniform thickness of the silicone material representing the mucosa. Afterward a circular cut was made over each implant in the mucosal simulation to expose it and reveal the implant platform.

Two straight multiunit abutments were attached to the middle implants and two angled screw-retained multiunit abutments (Implant Direct, USA) were attached to the distal implants. Parallel platform between the abutments was established on which the prosthesis framework was attached afterwards.

Steps of the hybrid prosthesis fabrication:

Four titanium sleeves (Implant Direct, USA) were screwed on the multiunit abutments, the proper height was marked to the level of the occlusal plan guided by the retromolar pad and were reduced using metallic disc to the determined mark. Blocking out the undercuts with soft wax was done and as a preparation step for scanning the lower cast, spraying the cast and the titanium sleeves using the scan spray (Renfert, USA) was done. Then it was scanned by the extraoral desktop scanner (Identica hybrid scanner, USA).

The fixed-detachable prosthesis was designed using the software (Exocad designing software) to replace the lost teeth till the first molar and the gingival tissues. Cut back was done on the facial surface for accepting the veneering material for the artificial teeth and gingival tissues. This design was sent to the CAM software and prepared for milling. According to the material used for the framework construction:

- For model I: Bio-High Performance Polyether, Brecam BioHPP blank (Bredent, Weißenhorner, Senden, Germany) was used.
- For model II: Polyether-ketone-ketone, PEKK blanks (Pekkton ivory, Cendres + Métaux SA, Switzerland) was used.

Finishing the milled framework was done and seated on the titanium sleeves to check the passivity of fit, sandblasting of the abutment holes of the framework and the titanium sleeves was done. The adhesive material was added on the titanium sleeves and visio-link primer for the framework abutment channel. Afterward the framework was cemented to the titanium abutments by dual cured resin cement (Bredent. sendes, Germany) and light cured for 90 sec.

Each framework was placed on the cast and was prepared for denture veneers using high impact polymethylmethacrylate composite teeth that were set and attached to the facial surface of the framework using wax, and a silicone index was prepared to keep the teeth position verified. Fig. (2) Later the veneers were removed for cleaning and returned back to their registered positions in the index. A special adhesive (Visio link Bredent, sendes, Germany) was applied on the inner surface of the veneers and the framework and light cure was applied for 90 sec.

Fig. (2): Silicone index with the veneers

Afterward the opaque (Opaquer combo.lign, Bredent, Germany) was applied on the framework to block the spaces lingualy and the excess material was removed. Setting of the teeth was done on the framework and adhesive composite (compo. lign, Bredent, Germany) was used for veneers cementation

Two stages of polymerization were performed; intermediate polymerization where hand lamp was used for the layers fixation then final polymerization was completed in a special UV curing unit (Bre lux power unit, Bredent, Germany), Afterwards the framework was finished and polished. Fig. (3)

Fig. (3): The final prosthesis with BioHPP framework

Installation of the strain gauges:

Four strain gauges (gauge length 1 mm, gauge resistance 120.4 ± 0.4 ohm) (Kyowa strain gauges, Japan) supplied with totally encapsulated grid and attached wires were used to assess the strains induced in the four supporting implants.

The prosthesis was unscrewed, the mucosa simulator was removed from the cast to install the strain gauges in their planned grooves. Two strain gauges were installed at the mesial aspect of the central implants while the other two were installed at the distal aspects of distal implants. They were placed parallel to the long axes of the implants and secured in position on the model with delicate layer of cyanoacrylate base adhesive cement. The wires of the strain gauges were embedded in grooves created in the base of the model and secured in position using bonding agent and adhesive tape to avoid any possibility of movement that may affect the accuracy of the records. Fig. (4A)

Load application and recording measurement

For load application, universal testing machine (Instron, USA) where standardized static vertical loads were applied on the planned loading points at range 0-60 N, which is correspondent to the moderate biting force. The strains induced by the applied load were assessed using four-channel strain-meter. The following recording steps were followed for the two studied models:

A-For bilateral loading

The model with fixed-detachable prosthesis screwed to the multiunit abutments was placed on the universal testing machine lower metal plate. The T-shaped load applicator bar was adjusted to touch the prosthetic teeth bilaterally between second premolar and first molar. Where spot grinding was done till simultaneous even contact between the terminals of the load applicator and the teeth were reached guided by the markings of the articulating paper.

The bilaterally applied load started from zero up to 60 N at a constant rate of 1 mm/min. Recording the microstrains of the four strain gauges was done to measure the strains developed at the previously mentioned aspects. When the load was fully applied, the readings were transferred from the four channels strain-meter to the microstrain units.

Adequate time was allowed for the strain gauges to return to the zero balance and to permit the resilient structures to rebound completely before applying the unilateral loading.

B- For unilateral loading

Unilateral load was applied perpendicular to the occlusal plane on the left side of the prosthesis, between second premolar and first molar, and represented the working side. Fig. (4B) while the right side was considered the non-loaded side. The applied load started from zero up to 60 N. The microstrains of the four strain gauges were recorded to measure the strains developed at same previously mentioned aspects.

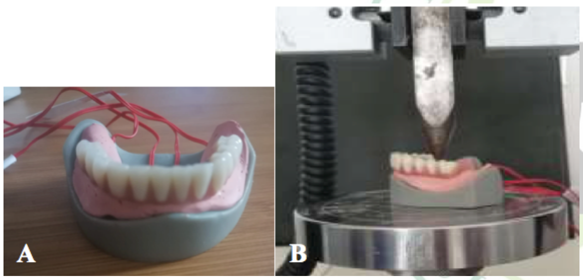

Fig. (4): A) Strain gauges installation, B) Unilateral load application between second premolar and first molar

The whole procedure was repeated five times for each model. After inspection of the obtained data, the sudden drop in the microstrain readings was detected. The mean of the last 10 readings recorded by each channel before the sudden drop were tabulated for each time of loading, then statistical analysis was performed to compare between the strains recorded in the studied aspects and from the two framework materials.

Statistical Analysis:

All data of the current study were collected and statistically analyzed using the statistical package for social science (SPSS 16.0) for windows. Paired t-test was used to compare between unilateral and bilateral loading, as well as between right and left sides within each group. Student T test was used to compare between the groups. The significance level was calculated at $P \leq 0.05$.

Results

Data was revealed as mean M and standard deviation SD for further analysis. A probability level of $P \leq 0.05$ was considered statistically significant. The results of this study were represented in (4) tables and (4) figures.

The mean values of the recorded microstrains at the mesial aspect of the central implants and the distal aspect of distal implants and their level of significance for the Model I Fixed-detachable prosthesis framework made from Bio-High Performance Polyether (BioHPP) and Model II Fixed-detachable prosthesis framework was constructed from Polyether-ketone-ketone (PEKK) when bilaterally and unilaterally loaded are presented in tables (1,2).

Regarding model I (BioHPP framework), the results presented in table (1), Fig. (5) revealed that during unilateral loading mean amount of microstrain induced at the mesial aspects of central implants and distal aspects of distal implants were 128.37 and 157.65 for the left side (loaded side), and 48.94 and 54.29 for the right side (unloaded side) respectively. Data obtained from this table revealed that unilateral loading induced higher microstrains at the distal side of the distal loaded implants; $p \leq 0.05$.

The mean amount of microstrains induced at the mesial aspects of central implants and distal aspects of distal implants during bilateral loading were 82.14 and 96.14 for the left side and 87.32 and 99.73 for the right side respectively. Although more stresses were induced on the distal implants compared to the central implants, statistical analysis of the data revealed insignificant difference $p > 0.05$.

Table 1: Mean, standard deviation and Paired-t test for the amount of microstrains induced at the implants for Model I (BioHPP framework) during loading.

Load	Aspect Side	Mesial central implants		Distal implants		*T*-value
		Mean	SD	Mean	SD	
Unilateral	**Left Loaded**	128.37	± 28.7	157.65	± 11.9	5.45*
	Right Unloaded	48.94	± 5.5	54.29	± 4.2	1.31NS
Bilateral	**Left**	82.14	± 16.5	96.14	± 4.3	1.61 NS
	Right	87.32	± 13.4	99.73	± 12.3	1.06 NS

*: Significant at P ≤ 0.05 NS: Non significant

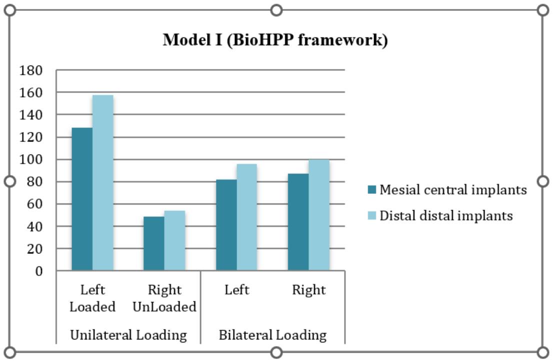

Fig (5): Mean amount of microstrains induced at the implants for Model I (BioHPP) framework duringunilateral and bilateral loading.

Regarding Model II (PEKK framework), during unilateral loading the results presented in table (2), Fig. (6) revealed that the mean amount of strains induced at the mesial of central implants and distal of distal implants are 97.27 and 116.65 for the left loaded side and 32.94 and 41.57 for the right unloaded side respectively. Statistical significant higher microstrains at the distal of distal implants p<0.05 than those induced on the mesial of central implant for left loaded side was detected

During bilateral loading the amount of strains induced at the mesial of central implants and distal of distal implants were 61.88 and 69.52 for the left side, and 63.53 and 71.66 for the right side respectively. Although more stresses were detected on the distal implants on both sides statistical analysis of the data revealed insignificant difference for the left and right sides p > 0.05.

Table 2: Mean, standard deviation and Paired-t test for the microstrain induced at the implants for model II (PEKK framework) during loading.

Load	Aspect Side	Mesial central implants		Distal distal implant		T value
		Mean	SD	Mean	SD	
Unilateral	**Left Loaded**	97.27	± 3.9	126.65	± 8.2	3.55*
	Right Unloaded	32.49	± 4.7	41.57	± 2.6	1.23NS
Bilateral	**Left**	61.88	± 2.4	69.52	± 2.6	0.83 NS
	Right	63.53	± 4.2	71.66	± 5.8	0.55 NS

*: Significant at P ≤ 0.05 NS: Non significant

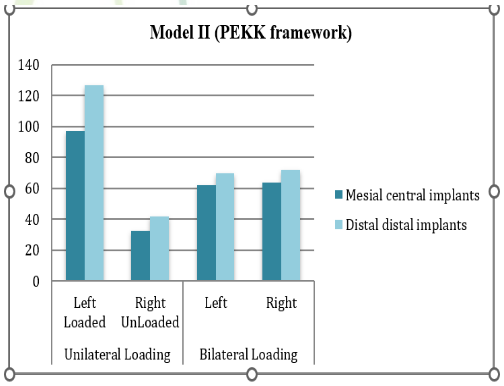

Fig (6): Mean amount of microstrains induced at the implants for Model II (PEKK) framework during unilateral and bilateral loading.

Comparing the two groups, the mean values of the recorded microstrains at mesial aspects of central implants and distal aspects of the distal implants when unilateral load was applied for Model I (BioHPP framework) and Model II (PEKK framework). The mean microstrains recorded at mesial aspects of central implants for the left loaded side was found to be 128.37 for Model I (BioHPP framework) and 97.27 for Model II (PEKK framework) as shown in table 3, Fig. (7). Statistically significant, P<0.05, more stresses were detected in model I compared to model II. The mean microstrain recorded at mesial aspect of the right unloaded central implants was 48.94 for model I (BioHPP framework) and 416.57 for model II (PEKK framework) respectively.

Statistical analysis of the data revealed insignificant difference between the two studied frameworks P>0.05.

Table 3: Mean, standard deviation and student-t test for the amount of microstrains induced on the implants for the studied models during unilateral loading.

Load	Side Aspect	Model I BioHPP framework		Model II PEKK framework		T value
		Mean	SD	Mean	SD	
Left loaded	Central implants	128.37	± 28.7	97.27	± 3.9	2.3NS
	Distal implants	157.65	± 11.9	116.65	± 8.2	5.64*
Right Unloaded	Central implants	48.94	± 5.5	32.49	± 4.7	1.87NS
	Distal implants	74.29	± 4.2	41.57	± 2.6	1.35NS

*: Significant at P ≤ 0.05 NS: Non significant

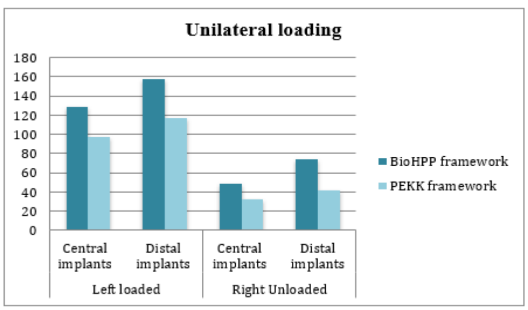

Fig (7): Mean the amount of microstrains induced on the implants for the studied models during unilateral loading.

The Mean values of the recorded microstrains at mesial aspects of central implants and distal aspects of distal implants when bilateral load was applied for model I (BioHPP framework) and model II (PEKK framework) are shown in table (4), Fig. (8). The mean microstrains recorded at the mesial aspects of the central implants for the left side was found to be 82.14 for (BIOHPP framework) model I and 61.88 for (PEKK framework) model II respectively. The mean microstrains recorded at the mesial aspects of the right central implants was found to be 87.32 and 63.53 for (BioHPP framework) model I and (PEKK framework) model II respectively. Although higher stresses was recorded for model I compared to model II, the difference was found to be statistically insignificant P>0.05.

The mean microstrains recorded at the left distal aspects of the distal implants was found to be 96.14 for (BioHPP framework) model I and 69.52 for (PEKK framework) model II as shown in table 4. Regarding the right side the mean values of microstrains was found to be 99.73 and 71.66 for (BioHPP framework) model I and (PEKK framework) model II respectively as shown in table 4. Statistical significant higher microstrains at the distal aspects of peripheral implant p<0.05 was detected in model I .

Table 4: Mean, standard deviation and student-t test for the amount of microstrain induced on the implants for the studied models during bilateral loading.

	Side Aspect	Model I BioHPP framework		Model II PEKK framework		T value
		Mean	SD	Mean	SD	
Left	Central implants	82.14	±46.5	61.88	±14	1.37NS
	Distal implants	96.14	±4.3	69.52	±2.6	4.62*
Right	Central implants	87.32	±13.4	63.53	±4.3	0.98NS
	Distal implants	99.73	± 12.3	71.66	±5.8	4.22*

*: Significant at P ≤ 0.05 NS: Non significant

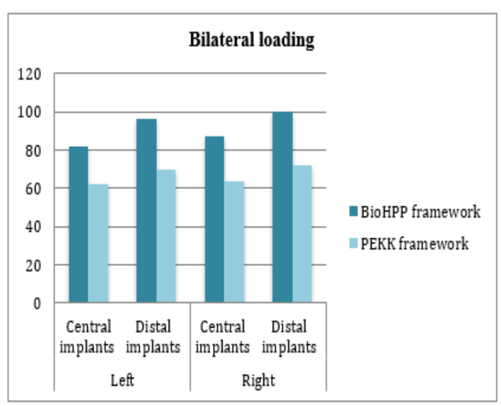

Fig. (8): Mean the amount of microstrains induced on the implants for the studied models during bilateral loading.

Discussion

Because of the existing disadvantages of conventional complete dentures, advancing technology and material improvements have been conveyed to generating novel treatment options. Using the All-on-4 treatment concept in conjunction with recent advances in dental materials mostly reduced the risk of morbidity, the required treatment time and increased the success rate of implants used in edentulous patients. This protocol that was specially developed to overcome the challenging prosthetic and surgical difficulties caused by the anatomical limitations, has increased its popularity and are used more commonly.[33]

Appropriate planning for the sub and superstructure materials that support the implant prosthesis is one of the key factors for long-term clinical success of the prosthesis. The material properties and its components geometric configuration have major impact on the transmission of the masticatory loads and stress distribution on the bone implant prosthesis assembly.[34] And there is continuous development in the dental materials and increased interest in esthetic dentistry, this study was done to investigate two recent materials developed with better properties from PEEK and are using CAD/CAM manufacturing technique.

This study adopted strain gauge stress analysis method to evaluate the strain on the supporting implants as it is considered highly accurate evaluating method as it can recognize very slight strains and surface deformities, and reproducible method of in vitro stress analysis.[30-32] Besides as an in vitro study it permits better control over variables (limit human variation) and to facilitate measurements of changes that occur.

3D printing technology is an additive process was used to fabricate the experimental models as there is accepted accuracy of stereolithgraphy technology. Rapid prototyping technique greatly facilitates the 3D objects recognition together with the speed of production with little material waste and accuracy and can manupilate several materials such as plastics, ceramics and metals, which are applicable to dentistry.[35,36] In addition to its advantages, it provides better build resolution, smoother surfaces, good chemical bonds and mechanical strength.[37] 3D printed model acquired accuracy might be attributed to the fact that they exhibit nil amount of internal stresses because of the method of fabrication of the model through building it layer by layer.[38]

The main requirement in fixed-detachable prosthesis is to optimize and enhance stress distribution and minimize forces transmitted to the implant. Thus BioHPP and PEKK were used in framework construction to be evaluated, as they are recent alterations of the main thermoplastic high performance polymer. Both has modulus of elasticity that is near to that of bone which help to dissipate the applied load and reduces the amount of stresses transmitted to the underlying implants.[24] Although all the increased applications of its use, there are few previous studies performed on high-performance polymer PEKK and further studies are needed.

The null hypothesis of this stress analysis study was rejected since the strains recorded from (BioHPP framework) model I was more than that recorded in (PEKK framework) model II although was not significant in right and left sides in bilateral and unilateral loading but the results revealed significant difference at distal surface of the distal implants than in central implants.

The results obtained from bilateral occlusal load application in this study revealed that there is no significant difference between the stresses induced in the supporting implants located in the right and left side in both studied models. This could be explained by implant-supported prosthesis provides cross-arch stabilization that in turn offers increased resistance to lateral forces provoked by masticatory function.[39] Furthermore, by its splinting effect it distributes the occlusal loads evenly, consequently, prevents overloading of each implant supporting the prosthesis, reduces mechanical complications and lowers the required number of implants.[40]

All on 4 concept was followed where among its advantages the increase in the anteroposterior spread using less number of supporting implants and reduces the length of cantilever. However, the presence of cantilever in the design used may explain the results recorded of significant higher strain at the distal aspect of the distal implants than the mesial of central implants.

In unilateral vertical load application, the strains recorded in the loaded side was more than that recorded in the unloaded side in both models. This may be explained by the rotational movement of the prosthesis that takes place and concentrates the load at the loaded side consequently transmits more stresses on the implants and the ridge.[41]

The mean microstrains recorded at the loaded side was significantly lower in (model II) compared to (model I). This may be attributed to their modulus of elasticity where it is 5 GPa for PEKK compared to 4 GPa for BioHPP which transmits less stresses to underlying supporting implants.[20,42]

Less strain values were recorded in the supporting implants for PEKK framework model compared to those with BioHPP framework which may be explained by the development in the material and being more rigid and the fact that the more rigid the used material is, the less the mobility of the prosthesis, the less stresses that are transmitted to the supporting structure. Despite their chemical similarities PEKK has better mechanical properties where higher compressive strength that is due to the addition of titanium dioxide (TiO_2) and presence of the second Ketone group that increases rigidity with its wear resistance and hardness.[24] These may explain the results of this study.

In this simulating in vitro study, the results obtained are descriptive, since using acrylic resin model with physical properties that doesn’t replicate the biomechanical nature of the bone. Other clinical parameters as tissues reaction, prosthetic maintenances and patient satisfaction are important factors for determining the treatment success. Thus, clinical studies are recommended to confirm the biomechanical outcome of these new materials.

Conclusion

Within the limitation of this simulation study, using polyether-ketone-ketone (PEKK) for constructing the framework of the prosthesis lead to favorable stress distribution and reduces the stresses induced to the supporting implants. Further clinical studies are required to confirm this finding.

Conflicts of interest

The author declares that there are no conflicts of interest.

Funding

Not applicable

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