

Stress Induced by Mandibular Screw Retained Hybrid Denture on “All-On-Four” Implant Distribution: Comparison between Three Different Hybrid Denture Materials: In-Vitro Study

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Abstract

Aim of The Study: To compare stress induced by three different denture base materials on implants retaining all on four fixed detachable dentures (Acrylic with metallic Substructure -BioHPP- all acrylic denture base material).

Material and Methods: This in-vitro stress analysis (case control study) was conducted on computer generated three dimensional model simulating a completely edentulous lower arch with four implants inserted in all-on-4 implant configuration to support and retain fixed detachable prosthesis. According to the framework material of the fixed detachable prostheses. In this study, we used three models were constructed according to the framework material: Model I: Fixed detachable overdenture made from acrylic resin (poly methyl methacrylate) reinforced by casted metallic framework (cobalt chromium alloy). Model II: Fixed detachable overdenture made from high performance polymer (BIOHPP). Model III: Fixed detachable overdenture made from acrylic resin (poly methyl methacrylate).

Results: Mean \pm standard deviation values of the recorded microstrains at lingual aspects of the central implants when unilateral load was applied. in the loaded side, model II showed lower significant difference compared to model I and III as P-value < 0.05 . For the unloaded side, the data obtained, showed that the amount of microstrains induced on the lingual aspects of the central implants for model I, II and III were, it was revealed that there was insignificant difference between all models as P-value > 0.05 . Mean \pm standard deviation values of the recorded microstrains at distal aspects of the peripheral implants when unilateral load was applied. Regarding the loaded side, the amount of microstrains induced on the distal aspects of the peripheral implants for model I, II and III was revealed that there was significant difference between all models as P-value < 0.05 . The unloaded side, it was revealed that there was insignificant difference between all models as P-value > 0.05 .

Conclusion: It was revealed that there was significant difference between all models in the loaded side of the central implants-as P-value < 0.05 , and the amount of macrostrains induced on the lingual aspects of the central implants was the lowest in models II in comparison to model I and III. It was revealed that there was insignificant difference between all models in the unloaded side of peripheral implants as P-value > 0.05 , and the amount of macrostrains induced on the distal aspects of the peripheral implants was the lowest in models II. It was revealed that there was significant difference between all models in the loaded side of peripheral implants as P-value < 0.05 , and the amount of microstrains induced on the distal aspects of the peripheral implants was the lowest in models II. The Fixed detachable overdenture made from high performance polymer (BIOHPP) distributes the occlusal load well and decrease the chance of implant overloading.

Keywords: BioHPP-High performance polymer, All-On-Four

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Introduction

Dental re-establishment and rehabilitation in edentulous patients can be achieved by using screw retained hybrid prosthesis, screw-retained metal ceramic prosthesis and cement-retained metal ceramic prosthesis. Use of screw-retained prosthesis is suggested for patients suffering from poor denture retention because this type of prosthesis can be easily placed and maintained.

Implant assisted over dentures and hybrid prosthesis provide good support and retention when compared to the traditional fixed prosthesis. With the development of computer-aided designs and the improvement of prosthetic materials, soft tissue loss can be easily substituted and even pink interdental papilla can be artificially created.

In general, hybrid prosthesis is the suggested treatment option for patients suffering from severe alveolar ridge resorption so implant assisted over dentures are now considered as a standard treatment for highly resorbed alveolar ridge patients.

The denture base resin is commonly based on poly methyl methacrylate (PMMA), which has several advantages such as brilliant esthetics, stability in the oral environment, and simplicity of repair. However, flexural fatigue has been considered as a influencing factor for fracture.

CAD-CAM (Computer-Aided-Designed, Computer-Aided Manufactured) is a design, fabrication and manufacturing process used for restorative and prosthodontic treatment procedures, using biocompatible materials including

alloys, ceramics and high-performance polymers. CAD-CAM also decreases chairside time and also produces good outcomes.

Poly ether ether ketone (PEEK) is an innovative material for creating CAD-CAM fixed and removable prostheses, because it is easier to mill than titanium and it is also easy to polish. Milling with poly ether ether ketone (PEEK) is highly suggested as the resulting non-allergic prostheses are lighter in color than those constructed of other materials, such as Co-Cr or titanium, and the milling process does not adversely influence the mechanical properties of the poly ether ether ketone (PEEK) material.⁽¹⁾

The aim of this study is to compare stress induced by three different denture base materials on implants retaining all on four fixed detachable dentures (Acrylic with metallic Substructure -BioHPP- all acrylic denture base material).

Material and method

This in-vitro stress analysis (case control study) was conducted on computer generated three dimensional model simulating a completely edentulous lower arch with four implants inserted in all-on-4 implant configuration to support and retain fixed detachable prosthesis. According to the framework material of the fixed detachable prostheses.

In this study, we used three models were constructed according to the framework material: Model I: Fixed detachable overdenture made from acrylic resin (poly methyl methacrylate) reinforced by casted metallic framework (cobalt chromium alloy) attached to the implants by screw- retained abutments. Model II:

Fixed detachable overdenture made from high performance polymer (BIOHPP) attached to the implants by screw-retained abutments. Model III: Fixed detachable overdenture made from acrylic resin (poly methyl methacrylate) attached to the implants by screw-retained abutments.

1-Construction of the 3D model:

A scan of completely edentulous educational model of mandibular arch was made; the model was scanned via 3Shape desktop scanner¹. Then STL file ("Standard Triangle Language" and "Standard Tessellation Language") was generated. In this STL file, four implant beds were designed representing the planned osteotomy sites for the four implants.

Four implant beds to receive conventional standardized interactive implants² 11.5 mm length and 3.7 mm diameter were planned. Two central implant beds planned to be at equal distances from the midline in the canine region and two peripheral implants angled up to an angle of 30 degrees in the second premolar region, The two central implants planned in the canine region with an axial orientation and the two peripheral implants planned with angulation in second premolar molar region.

The raw material used in production of the printed item is a photopolymer, which in fact is a mixture of acrylic acid esters and photo initiator³. (Figure 1)



Figure (1): 3D printed cast.

2-Implant insertion and Simulation of the mucosa:

Mucosa simulation was done via gingival mask material⁴ (Figure 2).



Figure (2): Gingival simulator

3-Preparation the lower cast for overdenture fabrication:

A- Multi-unit abutment attachment:

Angled multiunit abutments (screw-retained abutments) attached to the peripheral implants whereas straight multiunit abutments attached to the central implants using hex screwdriver to ensure parallelism⁵ (Figure 3)



Figure (3): 3D cast with implants with multi-unit abutments.

¹ Smart optics, activity 855 (Germany)optical scanner

² Nobel Biocare trademarks for All-on-4® treatment concept

³ ABS like resin grey (Taiwan)

⁴ Gingsil special silicone gingival mask soft , (dent-E-con)(Germany)

⁵ Multiunit abutment, Implant Direct, USA

4-Steps of fabrication the fixed detachable (screw retained) hybrid denture

A-Setting of artificial teeth and achieving the labial index

Setting of teeth done (poly methyl methacrylate modified anatomic artificial teeth)

of the prosthesis relative to the working model. The teeth removed from the wax-up and placed into their respective locations in the silicone putty index, and they luted into position with sticky wax. The index with the teeth onto the working model used as a guide for modifying the copings, reducing the height of the sleeves.

B-Model I: screw retained acrylic resin overdenture reinforced by metallic framework

The Plastic castable abutments were screwed to the multiunit abutments on the working model. The plastic sleeves were reduced to the level of the occlusal plane according to the anatomical and mechanical considerations, the reduction of plastic sleeves height was done by using a marker.

The designing of the frame within the confines of the trial hybrid denture teeth was done. The copings connected together using an acrylic resin material were used to serve as a foundation for the frame wax-up⁶

The index removed and waxing the framework done to follow and support the position of the teeth, retention beads and loops were added. (Sprueing and investing of the wax pattern and casting of the framework

was performed using the cobalt chromium alloy. After divesting, finishing, and polishing the framework, when divesting the casting, it is important not to sandblast the abutment interface. Then finishing and polishing of the casting was done and checked for a passive fit (figure 4)



Figure (4): Metallic framework after finishing and polishing Waxing -up, flasking, wax elimination, packing and curing of the heat-cured acrylic resin followed by deflasking, finishing and polishing of the denture was done then the denture was tried to fit to the cast to be passively seated⁷.

C-Model II: BIOHPP overdenture attached by screw retained abutments

The titanium sleeves were screwed into place on the multiunit abutments the Reduction of titanium sleeves height was done by using a marker to mark proper height of the sleeves to the level of occlusal plan.

⁶ Duralay, reliance dental mfg inc(USA)

⁷ Heat cured acrylic resin ,acrostone (Egypt)

Sleeves were screwed to the multi-unit abutments and blocking out the undercut by soft wax then spraying the cast and the titanium sleeves via the ⁸ for scanning the lower cast.

Scanning the lower cast via extraoral desktop scanner⁹ then designing the framework was done via exocad software designing.

The fixed detachable prosthesis that replace lost teeth and gingival tissues was designed using the software¹⁰ of the device then cut back was done for receiving the veneering material for both the artificial teeth and gingival tissues. The fixed detachable prosthesis was then milled in Polyether-ether Ketone (PEEK) BioHPP (high performance polymer) discs ¹¹(figures 5&6)

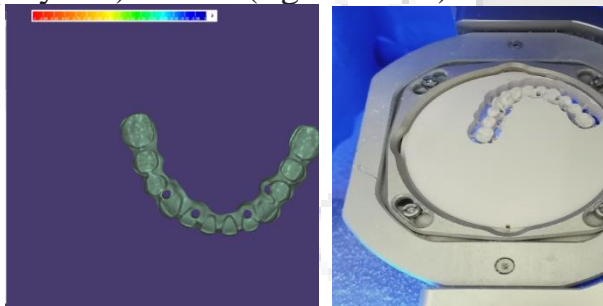


Figure (5): The final framework design

Figure (6): Milling the BIOHPP framework via 5-axis milling machine

Then finishing the milled framework was done and seated to the titanium sleeves to check the passivity of fit, sand

blasting of the abutment holes of the BioHPP framework and the titanium sleeves via the sand blasting device¹² Then adding the adhesive material (MKZ primer¹³ on titanium sleeves and visio-link primer¹⁴ for the BioHPP framework abutment channel) then the framework was cemented to the titanium abutments via (DTK dual cured resin cement 50-50)¹⁵ and light cured for 90 seconds (figures 7&8)



Figure (7): MKZ primer and visio-link primer

Figure (8): DTK dual cured resin cement

The BioHPP framework was returned to the cast, then preparing the framework for denture veneers ¹⁶(A2 for both anterior and posterior teeth) made from high impact poly methyl methacrylate were set and adhered to the framework by wax and then a silicone index was made to preserve teeth positions, the veneers removed afterwards and cleaned thoroughly to remove any wax traces and then returned to their positions in the silicon index, then a special adhesive ¹⁷ was applied on the BioHPP framework

⁸ Renfert scan spray, (USA)

⁹ Identica hybrid scanner, medit (USA)

¹⁰ Exocad designing software

¹¹ Brecam Biohpp blank 98,5mm×12mm (Bredent GmbH & Co.KG, Weißenhorner Str. 2, 89250 Senden, Germany).

¹² Oxyker duet, manfredi (Italy)

¹³ Mzk primer, bredent (sendes, Germany)

¹⁴ Visio-link pmma and composite primer, bredent (sendes, Germany)

¹⁵ Dtk-kleber dual hardening composite adhesive, bredent (sendes, Germany)

¹⁶ Novo-lign A2, bredent (sendes, Germany)

¹⁷ visio link bredent (sendes, Germany)

and the inner side of the veneers light cured for 90 seconds.

After that the opaquer¹⁸ was applied on the framework to block and fill the spaces between the frame lingually, then all was pressed using silicone key to be sure that all are closed and excess were removed (figure 9). Then setting of the teeth was done on the framework and adhesive composite¹⁹ was used for veneers cementation then a nano filled composite²⁰ dentin shade was layered to fill the gingival portions and the gum portions was constructed²¹ (figure 10)



Figure (9): The opaquer composite material

Figure (10): Composite material dentin shade and gingival shade

Polymerization was achieved via two stages, intermediate and final intermediate polymerization was done by hand lamp for fixation of the layers and final polymerization was then done in a special UV curing unit²² for 180 sec for compo. lign material and 360 sec in case of crea .lign material

After polymerization the BioHPP framework was finished by tungsten carbide bur and polished by goat hair brush and pumice.

¹⁸ Opaquer combo.lign , bredent (sendes ,Germany)

¹⁹ compo. lign , bredent (sendes ,Germany)

²⁰ Crea .lign dentin , bredent (sendes ,Germany)

²¹ Crea .lign gum , bredent (sendes ,Germany)

D-Model III: acrylic resin overdenture attached by screw retained abutments

The titanium sleeves abutment screwed to the multiunit abutments on the working model. The Reduction of sleeves height was done.

Then removing the index and setting up the denture teeth in wax following conventional denture procedures with the help of silicone index Then Processing of acrylic using conventional denture procedures with using long prosthetic screws during processing. This will maintain the screw access holes.

Waxing up, flasking, wax elimination, packing and curing of the heat-cured acrylic resin²³ followed by deflasking, finishing and polishing of the denture was done then the denture was tried to fit to the cast to be passively seated (figures 11&12)



Figure (11): the acrylic resin overdenture deflasking



Figure (12): Finished and polished acrylic resin overdenture

5-Strain gauge installation:

The strain gauges²⁴ used in this study were supplied with fully encapsulated grid and attached wires. The gauge

²² Bre lux power unit ,led full range system, bredent (sendes ,Germany)

²³ Heat cured acrylic resin ,acrostone (Egypt)

²⁴ kyowa strain gauges, Japan.

length was 2 mm, the gauge resistance was 120.4 ± 0.4 ohm and the gauge factor was $2.09 \pm 1.0\%$. Strain gauges were connected to lead wires 100 cm in length; a packing material insulated the wire used for the strain gauges. (Figure 13)



Figure (13): Stain gauge

To install the strain gauges, the denture was unscrewed, the mucosa simulator was removed from the cast, and the strain gauges were installed on the distal aspects of each peripheral implant and in the lingual aspect of the central implant. All the strain gauges were positioned parallel to the long axes of the implants. All strain gauges were bonded in position on the acrylic model with delicate layer of Cyano Acrylate base adhesive cement²⁵.

6-Loading test:

Universal Testing machine²⁶ used for applying standardized vertical static loads ranging between 0-100 Newton on the loading points, which is equivalent to the moderate level of biting force. The loading device consists of a base, frame, model fixture and the loading point. The base made from a steel sheet of metal 1 mm in thickness with an inverted U-shaped form.(figure 14)



Figure (14): Universal testing machine
A four-channel strain-meter was used to assess the strains induced by the applied load.

7-Load Application:

The model with the fixed detachable denture with All-on-4 configuration; Model I: acrylic resin overdenture reinforced by cobalt chromium metallic framework attached by screw-retained abutments was placed on the lower metal plate of the universal testing machine. Unilateral Load was applied vertically perpendicular to the occlusal plane on the left side to represent the working side between second premolar and first molar using T shaped load applicator. A T-shaped load applicator made to fit on the denture teeth unilaterally. Simultaneous and even contacts between the terminal ends of the load applicator and the artificial teeth on the loaded side of the model was achieved by spot grinding guided by articulating paper markings. A loading magnitude of 100 Newton was applied by turning the handle of the loading device specific number of complete turns. A red colored pointer was attached to the top end of the pushing plunger where it was locked in zero load position by a cap screw. The load applied increased from zero to 100

²⁵ Superglue,Egypt

²⁶ Instron (3365),USA

N at a constant rate of 1 mm/min. The microstrains of each strain gauge recorded to measure the strains developed at the lingual and distal aspects of the implants fixtures for unilateral load application. Once the load was completely applied, the microstrain readings were transferred to microstrain units. Data was analyzed using the software²⁷ and statistically analyzed. The same steps were followed to assess strains induced on right posterior implant; enough time was given to the strain gauges to be in zero balance and to allow complete rebound of the resilient structures. The same steps were followed for Model II: BioHPP overdenture attached by screw-retained abutments and for Model III: acrylic resin overdenture attached by screw retained abutments. The obtained data was inspected; the sudden drop of the reading was detected. The mean of the last ten readings obtained from each channel before the incidence of the sudden drop of the measured microstrains were tabulated for statistical analysis to compare between strains obtained from the studied aspects and from the three treatment modalities.

8-Statistical Analysis:

The collected data were obtained through case control study performed using laboratory examination on selected models according to selected eligibility criteria. Data were statistically analyzed by Microsoft Excel[®] 2016²⁸, Statistical Package for Social Science (SPSS)[®] Ver. 24²⁹, and Minitab³⁰ statistical

software Ver. 16. Data was revealed as mean and standard deviation for further analysis. The results of this study were represented. At first, independent test was performed for comparison between microstrains induced between peripheral and central implants for each group. Finally, One Way Analysis of Variance (ANOVA) test followed by Tukey's post hoc test for multiple comparisons was performed between all groups for each peripheral and central implants. The level of significance was calculated at $P \leq 0.05$.

Results

Strains induced to Central Implants on Model I, II and III:

Mean \pm standard deviation values of the recorded microstrains at lingual aspects of the central implants when unilateral load was applied. Regarding the loaded side, the data obtained, showed that the amount of microstrains induced on the lingual aspects of the central implants for model I, II and III were (61.62 \pm 16.88), (49.76 \pm 2.67) and (61.30 \pm 16.80) respectively. Using One Way Analysis of Variance (ANOVA) test for comparison between all models in the loaded side followed by Tukey's post hoc test for multiple comparisons, model II showed lower significant difference compared to model I and III as P-value < 0.05. For the unloaded side, the data obtained, showed that the amount of microstrains induced on the lingual aspects of the central implants for model I, II and III were (49.97 \pm 2.73), (6.94 \pm 1.90) and (8.38 \pm 6.41)

²⁷ Instron Bluehil LE

²⁸ Microsoft Cooperation, USA.

²⁹ IBM Product, USA.

³⁰ Minitab LLC, USA.

respectively. Using One Way Analysis of Variance (ANOVA) test for comparison between all models in the unloaded side followed by Tukey`s post hoc test for multiple comparisons, it was revealed that there was insignificant difference between all models as P-value > 0.05, as listed in table (1).

Table (1):): Descriptive and Comparative Evaluation of Strains induced to Central Implants on Model I, II and III:

	Model I	Model II	Model III	P-value
Loaded side	61.62±16.88a	49.76±2.67b	61.30±16.80a	0.00**
Unloaded side	49.97±2.73a	6.94±5.90b	8.38±2.41b	0.00**

Model I; fixed detachable overdenture made from Polymethyl methacrylate reinforced by casted metallic framework attached to the implants by screw retained abutments

Model II; Fixed detachable overdenture made from High Performance Polymer BIOHPP attached to the implants by screw retained abutments

Model III; Fixed detachable overdenture made from Polymethyl methacrylate) attached to the implants by screw retained abutments

M; Mean, SD; Standard Deviation, P; Probability Level

Means with same superscript letter in the same row were insignificant different

Means with different superscript letter in the same row were significant different

***significant Difference*

Strains induced to Peripheral Implants on Model I, II and III:

Mean ± standard deviation values of the recorded microstrains at distal aspects of the peripheral implants when unilateral load was applied. Regarding the loaded side, the data obtained showed that the amount of microstrains induced on the distal aspects of the peripheral implants for model I, II and III were (169.83±19.13), (118.20±32.38) and (140.19±38.41) respectively. Using One Way Analysis of Variance (ANOVA) test for comparison between all models in the loaded side followed by Tukey`s post hoc test for multiple comparisons, it was revealed that there was significant difference between all models as P-value

< 0.05. For the unloaded side, the data obtained, showed that the amount of microstrains induced on the distal aspects of the peripheral implants for model I, II and III were (31.21±8.55), (12.88±3.53) and (22.76±6.24) respectively. Using One Way Analysis of Variance (ANOVA) test for comparison between all models in the unloaded side followed by Tukey`s post hoc test for multiple comparisons, it was revealed that there was insignificant difference between all models as P-value > 0.05, as listed in table (2).

Table (2): Descriptive and Comparative Evaluation of Strains induced to Peripheral Implants on Model I, II and III:

	Model I	Model II	Model III	P-value
Loaded side	169.83±19.13 ^a	118.20±32.38 ^b	140.19±38.41 ^b	0.0001**
Unloaded side	31.21±8.55 ^a	12.88±3.53 ^b	22.76±6.24 ^b	0.3086*

DISCUSSION

This study was carried out in-vitro to allow for better control over variables and to facilitate measurements of changes which occur. In vitro study was carried out as it seemed beneficial in providing valid comparative data excluding the effect of variation in the tissues overlying the ridge and the form and quality of supporting ridge. ⁽²⁾

Scanning of mandibular model used for educational purpose was used for this study. The usage of educational model eliminates the effects of the complex geometry and physiology of dental and oral structures on the results of this study. ⁽³⁾

The test model used in this study was fabricated utilizing 3D printing technology, This is justified due to the good accuracy of stereo lithography technology, Rapid Prototyping technology has attracted enormous interest among researchers because it greatly facilitates the realization of three dimensional objects as well as the speed of production with high accuracy, It was found that the lowest strain values of passivity of fit were recorded in Stereo lithography fabricated prosthesis, Accuracy of 3D printed model might be attributed to the fact that they exhibit no or nil amount of internal stresses due to the mode of fabrication through building the cast layer by layer. ⁽³⁾

It has been suggested that BioHPP frames be connected to titanium cylinders directly screwed to a fast and fixed abutment, thus enabling better fit assessment using radiographs. This would also simplify the CAD/CAM production of BioHPP frameworks and reduce wear or BioHPP ⁽⁴⁾.

Veneering BioHPP frameworks with composite materials like will enable better blending of pink esthetics to oral soft tissue when compared to conventional complete denture materials. Premanufactured veneers can be easily connected to BioHPP, and final white esthetics could be assessed at the try-in phase. ⁽⁵⁾

Strain gauges have been used to study stresses induced in dental structures. They allow in vivo and in vitro measurement of the forces on oral implants and supporting structures. Strain gauges can be used to clarify the biomechanical performance of implant-

supported prosthesis simulating the variation of number or inclination of implants thus it can be used to assess the effect of the number of abutments and inclination of distal implants on the axial forces and bending moments in implant supported prosthesis ⁽⁶⁾.

It is very difficult to reproduce chewing pattern by in vitro studies, 100N loading magnitudes were applied in order to correspond with the maximum chewing force, which range between 50-100 N, representing the normal masticatory forces. As much of chewing activity are carried out unilaterally, unilateral loading was applied ⁽⁷⁾

Regarding to central implants the unilateral loading revealed significant difference between the acrylic, conventional cobalt chromium and BioHPP fixed detachable prosthesis on the average stresses falling on the four implants and their supporting structures and there is significant difference between loaded and unloaded side, as stresses falling on the implants in the loaded side were more than stresses in the non-loading side in all models.

The results showed that BioHPP transmit lower stresses to central implants than acrylic ,conventional cobalt chromium fixed detachable prosthesis ,This may be explained by the fact that lower modulus of elasticity of crown material will absorbs more energy from the applied load, and transfers less energy to the underlying system. In other words, occlusal material with a low modulus of elasticity, like acrylic resin or BioHPP will damp the occlusal impact forces, thus

decreases its effect on the bone implant interface. ⁽⁸⁾

Regarding to peripheral implants the unilateral loading revealed significant difference between the acrylic, conventional cobalt chromium and BioHPP fixed detachable prosthesis on the average stresses falling on the four implants and their supporting structures and there is significant difference between loaded and unloaded side, as stresses falling on the implants in the loaded side were more than stresses in the non-loading side in all models.

The results showed that BioHPP fixed detachable prosthesis transmit lower stresses to peripheral implants than acrylic, conventional cobalt chromium, this may be attributed to the lower modulus of elasticity of BioHPP Also, this study was shown that when a load was applied, it was found that less stresses falling on the implants retaining BioHPP fixed detachable prosthesis. This may be attributed to that called off-peak property of the BioHPP as it presents an elastic behavior comparable with bone and reduces stress on implants. ⁽⁹⁾

Conclusion

Widely distributed implants cause proper distribution of imposed occlusal load. It was revealed that there was insignificant difference between all models in the unloaded side of the central implants- P-value > 0.05. and the amount of microstrains induced on the lingual aspects of the central implants was the lowest in model III. It was revealed that there was significant difference between all models in the loaded side of the central implants-as

P-value < 0.05, and the amount of macrostrains induced on the lingual aspects of the central implants was the lowest in models II in comparison to model I and III. It was revealed that there was significant difference between all models in the unloaded side of peripheral implants as P-value < 0.05, and the amount of macrostrains induced on the distal aspects of the peripheral implants was the lowest in models II. It was revealed that there was significant difference between all models in the loaded side of peripheral implants as P-value < 0.05, and the amount of macrostrains induced on the distal aspects of the peripheral implants was the lowest in models II. The Fixed detachable overdenture made from high performance polymer (BIOHPP) distributes the occlusal load well and decrease the chance of implant overloading.

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