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Research Paper: *Investigating the Stress DistributionApplied to Edentulous Ridge from Polyamide and Cbalt-Chrome Removable-Partial-Denture usingThree-Dimensional Finite-Element-Analysis*

Mehran Bahrami[1], Bahareh Shakeri[2], Maryam Memarian[3*]

[1]*Associate professor, Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.*
[2] *Doctor of Dental Surgery, Private Office, Tehran, Iran*
[3] *Associate professor, Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences,Tehran, Iran.*

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ABSTRACT

Introduction: The objective of this study was to compare the Von-Mises-stress (VMS) distribution applied to the edentulous ridges from a Polyamide RPD (PRPD) with those from a Cobalt-Chrome RPD (CCRPD).

Materials and Methods: A patient with mandibular Kennedy Class I, Mod I was selected. The patient's CBCT was cut off at 1 mm sections from the axial dimension. DICOM files were created. A three-dimensional-bone-model was prepared by segmenting the DICOM files and loading them in MIMICS software and the necessary modifications were applied on them using Geomagic software. The three-dimensional-designs were first developed using Exocad2016 CAD software. An extensive force equivalent to 150N was applied. Abaqus Software was used in order to meshing. Then the stresses applied on the left and right sides of the edentulous ridges were measured.

Results: In both models, the highest distribution of VMS in the edentulous ridges was observed exactly distal to the abutment teeth adjunct to the distal-extension-areas. In CCRPD, the mean stress on the left-edentulous-ridge was 220kPa and on the right-edentulous-ridge was 100kPa. In PARPD, the mean stress on the left-side-edentulous-ridge was 950kPa and on the right-side-edentulous-ridge was 600kPa. The amount of stresses on the edentulous ridges in the PARPD model (form 280Pa to 950PA) were too much less than those of CCRPD model (from 50kPa to 220kPa).

Conclusion: The polyamide bases can be flexed due to the applied forces and the forces can be distributed in them. So that PRPD can transfer very slight stresses to the underneath surfaces compared to CCRPD.

*** Corresponding Author:**
Maryam Memarian.
Address: Department of Prosthodontics, School of Dentistry, Tehran University of Medical Sciences,Tehran, Iran.
Tel: +98 (34) 88095465
E-mail: memarian@sina.tums.ac.ir

Introduction

Replacing the missing teeth is the most important priority in reconstruction of the defects and also regaining the patient's function and mastication (1). Some patients may have to choose removable-partial-dentures (RPD) instead of implant-assisted-prostheses for various reasons including systemic diseases, anatomical limitations, and economic problems (2). Casting RPD is generally-approved and is well-documented in the text books. The rigidity of the Cobalt-Chrome removable-partial-denture (CCRPD) provides all the necessary requirements such as support, retention, and cross-arch-stability. Of course, in some situations such as distal-extension RPDs, Cobalt-Chrome is not a suitable material for fabrication of the retentive clasps due to its rigidity which can cause detrimental forces to the abutment teeth. Sometimes, it is advised to use clasps with stress-breaker-property such as wrought-wire-clasps (3). In addition, increased demand for beauty among patients has caused the emergence and prevalence of RPDs without metal clasps such as thermoplastic-polyamide removable-partial-denture (PRPD) in the recent years.

Nylon thermoplastics are a sub-group of polyamide materials, which were first introduced in 1950 for the construction of RPDs. The crystalline structure of nylon makes it undissolvable, resistant to heat, strong, and formable. In addition, polyamide has high elasticity and is not toxic. As the process of polyamide fabrication is heat-curing, it can cause minimum shrinkage and deformity during its construction compared to chemical polymerization of acrylic in CCRPD (4). This material is almost tough. It is resistant to power strokes and also the applied forces during insertion and removal of RPDs (2,5). Patients feel comfortable with PRPDs because of their thinness and lightness (6,7). This material provides an acceptable level of beauty and has high biocompatibility (2,8). PRPDs do not usually need preprosthetic surgeries before impression making, because in most situations they may provide acceptable retention using the remained undercuts (7).

Despite the advantages of polyamide materials, using them as denture-base-materials still has some limitations (9), for example polyamide resins have high-elasticity-coefficients (4). It seems that this property leads to large displacement of the RPD and may apply excessive forces on the underlying mucosa and bone, especially in the mandible (9). However, Sharma A and Shashidhara HS explained that the flexibility of the major connector in the thermoplastic RPDs can play the stress-breaker-role in 2014. According to their study, the flexible base of these prostheses can "float" on the mucousa and may lead to the force distribution (10).

The major-connector-elasticity in a PRPD acts like a double-edged knife; it is like a stress breaker that is desirable in free-end RPDs, but on the other hand it may cause soft-tissue-irritation. About the mechanical properties of thermoplastic resins, some researchers (2,5,11,12) believe that because of high flexure of thermoplastic arms, too much stress cannot be applied on the abutment teeth and the edentulous ridge. However, other researchers (6,9,13-16) explained that these mechanical properties of thermoplastic resins may cause excessive deformation of the denture base which can consequently apply high detrimental stress on the abutment teeth and the edentulous ridges.

Although there are various articles in the literature which have discussed and compared characteristics of different clasps types in RPDs (17-20), but there is not any similar article to the current study.

The objective of this study was to investigate and compare the stresses applied on the edentulous ridges from a PARPD and from a CCRPD using three-dimensional finite-elements-method (3DFEM). There are too rare studies in the literature about this important topic. According to the null hypothesis of the current study, there were no differences between these RPDs considering the applied stresses on the edentulous ridges of both sides.

Materials and Methods

In this study, among the referred patients to the Implant Department of Tehran University of Medical Sciences, a patient with partially-edentulous-mandible, Kennedy Class I, and modification I (i.e. the left second premolar was pier abutment) was selected. The patient had already a CBCT for implant- insertion-surgery. Primary impressions were taken from the patient twice using irreversible-hydrocolloid and two casts were poured. In order to construct a three-dimensional-jaw-model, the patient's CBCT data was cut in the form of 500 axial images, and was loaded using the MIMICS software. The patient seeked for implant-supported-implant restorations and did not accept any kind of RPDs. The CBCT was already taken from the patient for implant surgery.

For modeling CCRPD, a medium-bodied-additional-silicone-impression was taken from the patient with a special tray and the cast was poured with dental stone. The cast on the proximal plates of the abutments and the lingual surfaces of the anterior teeth (i.e. guiding planes) was surveyed. The abutment teeth were slightly reshaped and modified on the cast for optimal designing of the CCRPD (i.e. the undercuts for retentive arms were reshaped and the rest seats were prepared). 20-gauge-undercuts were preferred on the mesiolabial of the canines, and the mesiobuccal of the second premolar for wrought-wire-clasps. A mesial-rest was prepared in the left-second-premolar and two cingulum rests were prepared on the canines. The designed major connector for CCRPD was lingual plate.

For modeling the crowns of teeth, scan casts (Smart optical 3D scanner, Open technologies, Italy) were used, and data were loaded in 3D Geomagic (Geomagic, 2012, 3D Geomagics Systems, USA) and Rhino (Rhinoceros, Mcneel, North America). As there were two casts with different abutments preparations and reshaping (one suitable to CCRPD and the other suitable to PRPD), both casts were scanned separately. So that two models of the teeth crowns and two mandibles were modeled. To obtain the external limits and the thickness of gingiva and mucosa, the scan casts were used. Using Rhino software, 0.2mm-thickness periodontal ligament was modeled around each tooth.

In this study, bone, teeth, mucosa, and periodontal fibers were considered as isotropic, linearly elastic, and homogenous similar to other original articles used 3D FEM (21,22).

Accordingly, the mandibular jaw was three dimensionally modeled as a Kennedy Class I, modification I model with the following dentition: (teeth #43, 42, 41, 31, 32, 33, and 35 as a pier abutment). The designing of CCRPD was performed by CAD method using Exocad 2016 software (Exocad dental CAD, Exocad, Germany) considering the acceptable thicknesses for the RPD elements and the amount of relief needed (i.e. 24-gauge lingual plate, 1mm saddle, 20 gauge relief under saddles, 0.9-1mm thickness wrought wire, 1.5mm occlusal rest seats, 2×2mm tissue stops) (3,23). The outputs were as stl files. Then, the performed design of CCRPD was transformed into three-dimensional models using Geomagic and Rhino softwares. The outputs were as step files.

In this software, it was impossible to design an acrylic resin along with Cr-Co framework, so that this limitation was compensated during the prosthesis modeling, using Rhino software. In order to designing and modeling the acrylic resin in the Rhino software, 2mm of the mucosal surface was offset (2mm is the thickness of the acrylic-resin-extension on the residual ridge). So that Cr-Co framework was embedded in the acrylic resin. Finally, the three-dimensional model of CCRPD was placed in the correct position relative to the mandible and the related teeth, using the Geomagic software. The Geomagic-software-outputs were transmitted to the Abacus software (Abaqus, CAE 6.9; Inc. Pawtucket, RI) for meshing.

The sequence of PARPD designing was identical to that of CCRPD (i.e. primary and final impression making from the patient again, surveying and designing the cast, scanning the cast, CAD the RPD with stl outputs, and transforming the CAD to step files).

The cast was surveyed for paralleling the guiding planes and to find the existing undercuts for polyamide-retentive-clasps. As 20-gauge undercuts are needed for these clasps, the abutments were selectively reshaped, accordingly. Of course, these clasps should cover the gingiva in contrast to the Cr-Co clasps. But the extension of PRPD base on the supporting tissues were designed identical to that of CCRPD base. The major connector was also lingual plate. So that the designing of both models were as similar as possible to each other, without breaking the principle rules of clinical designing.

After scanning the cast with Smart scanner, it was CAD with Exocad software. It should be noted that the 3D designing of both RPDs were included only the base and clasps. All the artificial teeth were not designed in both RPDs, because there were same in both models and were eliminated for the simplicity.

Stl output of CAD was used for modeling with Geomagic and Rhino softwares. Then like CCRPD the 3D model of PRPD was placed in the correct position relative to the mandible and the related teeth, using the Geomagic software and its outputs were transmitted to the same Abacus software for meshing.

The amounts of force applied to the food are different in complete denture wearers, RPD wearers, and those with natural dentition. According to Shillingburg, it is 26Ibs in RPD, 54.5Ibs in fixed prosthesis, and 150Ibs in natural dentitions. According to Craig's textbook the occlusal forces are between 65N to 235N in RPD wearers (24). In this study, 150N force was selected for both models.

The boundary conditions were as follows; the mandible was considered constant (i.e. not moving), the mechanical properties of the materials were in accordance with table 1 (21-26).

The connection type was defined as node-to-node form (24-29). An extensive force equivalent to 150N was applied in the multipoint constraint (MPC) and general-static form, on the RPD-artificial-teeth areas (i.e. on the distal-extension-areas of both sides of the models). MPC means that the force is applied from an imaginary point on top of the occlusal surface on the specific surfaces of the RPD (in this study, the distal extension areas). The results of meshing are presented in table 2. After meshing, the processor of software displayed the results.

Table 1- Mechanical properties of the materials

Type of material	Young's modulus (GPa)	Poisson ratio	Density g/cm3
cobalt-chrome	220	0.33	7.6
Acrylic resin	3	0.35	1.18
Polyamide resin	2.4	0.4	1.02
Wrought wire	180	0.33	7.74
Cortical bone	14.7	0.25	1.74
Periodontal fibers	0.0689	0.45	--
Mucous membrane	0.001	0.37	--
Dentin	17	0.31	2.1

Table 2- properties of mesh, element, and node.

Model	Mesh type	Number of elements	Number of node
CCRPD	linear tetrahedral elements of type C3D4	1107099	227772
PARPD	linear tetrahedral elements of type C3D4	6625719	1281308

Results

The maximum stress applied on the edentulous ridge in CCRPD was in the areas near the terminal-abutment-teeth. In general, on the left side, it was more than the right side due to the smaller loading-surface-area. As moving toward the posterior and both sides of the edentulous ridges or toward the anterior teeth, which were not the abutments, stress levels decreased. The mean stress on the left-edentulous-ridge was 220kPa and on the right-edentulous-ridge was 100kPa. By moving toward the posterior of the ridge, stress level decreased up to 50kPa (Fig. 1).

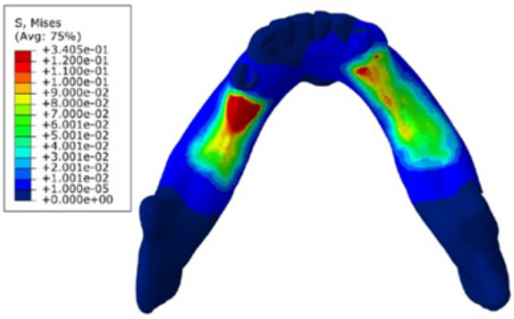

Fig. 1

Bahrami B, et al.Investigating the Stress Distribution Applied to Edentulous Ridge from Polyamide and Cobalt-Chrome Removable-Partial-Dentures using Three-Dimensional Finite-Element-Analysis. Journal of Dentomaxillofacial Radiology, Pathology and Surgery. 2020; 9(4):11-19. http://dx.doi.org/

Maximum and minimum stresses on the left-edentulous-ridge from CCRPD was 220KPa and 50KPa, respectively. Maximum and minimum stresses on the right-edentulous-ridge from CCRPD was 100KPa and 50KPa, respectively. The amount of current stresses in the CCRPD, itself was higher in the region of the denture base that was adjacent to the abutment teeth, and stress level decreased gradually and uniformly, as moving to the posterior, and medial and lateral sides of the denture base. The maximum amount of current stress in the CCRPD was in the distal of left-second-premolar (i.e. 90kPa), and after that was in the distal of right canine (i.e. 60kPa). On both sides, by moving toward posterior areas and both sides of RPD, the stress levels decreased and reached to 20kPa (Fig. 2).

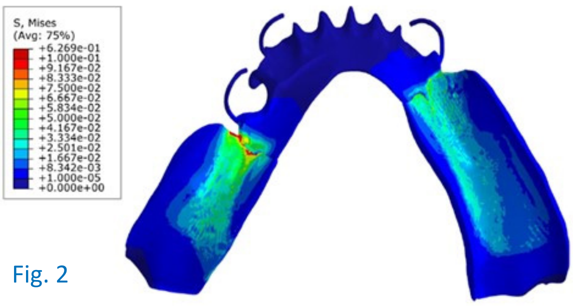

Fig. 2

The maximum stresses applied on the edentulous ridges in the PRPD was in areas close to the abutment teeth, similar to the CCRPD. In general, the stress was more on the left side than the right side due to the smaller-loading-surface. As moving toward the posterior area of the ridge and to the anterior-non-abutment-teeth, stress levels decreased.

The mean stress on the left-side-edentulous-ridge was 950kPa and on the right-side-edentulous-ridge was 600kPa. As moving toward the posterior area, the stress levels decreased up to 280kPa (Fig. 3).

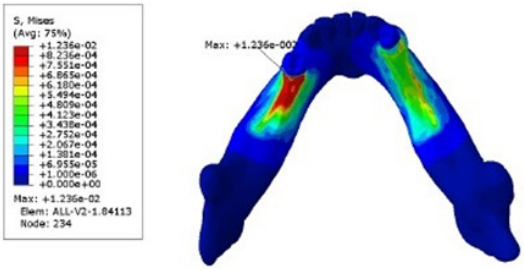

Fig. 3

The mean current stresses in PRPD, in the areas with the highest concentration of stress (i.e. the distal proximal plates of left-second-premolar and right canine) were 1.5-3MPa. The stress reached to its minimum level at the place where the force was applied (i.e. 200kPa), and in the posterior base (i.e. less than 500kPa = 0.5MPa) (Fig. 4).

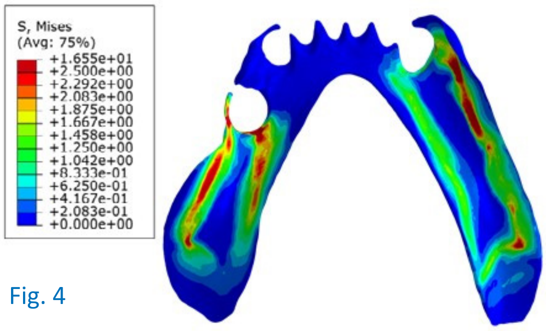

Fig. 4

Discussion

In this study, the stresses applied to the edentulous ridges and the current stresses in the PRPD and CCRPD were compared using 3D FEM. The null hypothesis was rejected, as the mentioned stresses were different in the studied RPDs.

The support of PRPD, is mainly provided by the edentulous ridges due to lack of rests. So that it seems reasonable that the maximum stress from PRPD is applied on the residual ridges and less stresses are applied on the teeth. But as there are rests in CCRPD, the maximum stress is applied on the rest seats of the teeth and less stresses are applied on the edentulous ridges. So that it may be assumed that the stresses on the edentulous ridges in the PRPD model without any rests would be more than those in CCRPD model which had rests. However, vice versa is true; the amount of stresses on the edentulous ridges in the PRPD model (form 280Pa to 950Pa or 0.28KPa to 0.95KPa) were much less than those of CCRPD model (from 50kPa to 220kPa or 50000Pa to 220000Pa). These significant differences in the stresses applied on the edentulous ridges may be attributed to the elasticity and stress-breaking-properties of nylon-bases-RPDs. In the other words, PRPD can absorb the stresses in itself and will transfer too little stresses on the ridges and the teeth. Sharma A. and Shashidhara HS explained that the flexibility of the major connector in flexible RPDs plays the role of stress breaker in 2014 (10). According to their article from the clinical point of view, the flexible base of these prostheses can bend during force application and may deform and float on the underlying tissues. These bases can completely match with the mucosal surface during continuous deformation of the oral mucosa. So that, it leads to the release of the force within the structure of the prosthesis base, and consequently its application on a large surface of the edentulous ridge. According to our study, the flexible base of the PRPD was transformed and bent due to the applied force, and with a wide force distribution it resulted in a reduced stress concentration per unit area (i.e. from 280 to 950Pa).

Takabayashi Y. also pointed out that thermoplastic prostheses through force distribution at a larger surface, can relieve the pain caused by excessive local pressure applied from CCRPDs onto the residual ridge (30). Takabayashi and Sharma et al studies were completely consistent with the results of the current study.

In CCRPD, because of its hardness and rigidity, force cannot distribute in the structure of the base. So that the stress was concentrated on the crest of the ridge in free-end-edentulous-areas (i.e. 100kPa on the right side and 220kPa on the left side). However, in textbooks of prosthodontics, the rigidity of the major connector is a fundamental and important principle. Because it causes the force to be distributed uniformly throughout the edentulous ridge and the abutment teeth (31).

In fact, during applying a vertical force to the tissues and without considering the horizontal displacements of the RPD base, CCRPD transmits one part of the "force" to the abutment teeth and the other part to the residual ridges, because of its rigidity. However, a PRPD transmits most of the "force" to the residual ridge. Of course, it does not necessarily mean that the PRPD may transmit more "stress" to the underlying ridges or the CCRPD may apply more "stress" on the abutments. It was clearly shown in this study that the PRPD can distribute the "forces" on a wider surface and can transmit lower "forces" to each unit of the residual-ridge-surface compared to the CCRPD, due to high elasticity and flexibility of PARPD. In the studied Kennedy Class I modification II, PRPD applied very little "stress" on the edentulous ridge.

However, it should be noted that the great amount of current stresses distributed in a PRPD, despite the elastic memory of these materials, can cause permanent distortion of the prosthesis, and consequently may result in the loss of its match with the underlying tissues. And even if assuming that the material of a PRPD has ideal flexural strength, proportional limit, and elastic memory and may not undergo permanent distortion (13), the elasticity of PA materials lead to instability of these RPDs during applying functional forces that should not be easily overlooked. Because the displacement of the RPD base can lead to undesired stresses (32).

As a general principle, since all RPDs are not fixed to their underlying tissues, they are displaced by the masticatory forces. This displacement also causes stress. This situation is more severe in PRPDs, due to the elastic nature of its constructing materials. In this regard, Muraki H. et al also explained that as the horizontal displacement of the RPD decreased, the stress concentration in the periodontal fibers reduced, significantly (33). Therefore, one of the disadvantages of PRPDs is their lower stability than CCRPDs.

The results of Jiao T. et al study in which photoelastic method was used, showed some similarities to the current study (34). They found that the patterns of stress distribution on the abutment teeth and edentulous ridge were almost similar in the studied prostheses. Similar to the current study, the stress was mainly concentrated in the edentulous area adjacent to the abutment teeth adjunct to the free-end-distal-extension-area, and as moving toward the posterior-edentulous-ridge and anterior-non-abutment-teeth, the stress level was reduced. Of course, Jiao T. et al concluded that all-acetal-resin RPD applied more stress onto the edentulous ridge, compared to the CCRPD. However, our study showed that PRPD transmitted too little stress to its underlying ridge compared to the CCRPD. The main difference of these different results can be attributed to the different methods of our study with Jiao T. et al study. In fact, photoelastic method is not suitable for evaluating the stress applied on the supporting structures of metal prostheses such as CCRPD and cannot properly compare these RPDs with prostheses of other types.

Wadachi J et al. in their study showed that the amount of force applied by PRPD to the underlying-edentulous-ridge was much higher compared to those applied by polyester RPD and CCRPD (16). It seems quite reasonable that in Kennedy Class III patients, CCRPD shows little bending and displacement during applying the force, because of its rigidity. CCRPD transfers most of the applied force to the adjacent-abutment-teeth, and transfers little force to the edentulous ridge. In contrast, the PRPD base, deforms according to its underlying tissues after force application, due to its high elasticity. PRPD transmits the major of applied force on the edentulous ridge (unlike the CCRPD). In

PRPD, the force applied on the edentulous ridge was large in the place of force application (31). However; this does not necessarily mean that in PRPD, too much stress may be applied on the edentulous ridge, because of the nature of the prosthesis which can release the "force" extensively and can apply little "stress" on the residual-ridge-surface-area.

The current stress in the base of CCRPD was uniform and balanced; while the current stress in the flexible PRPD was different and non-uniform. This was due to the difference in the hardness of their bases. In a flexible base such as PRPD, on the sides of the place where the force is applied, the sides of the prosthesis base is distorted and flexed due to its high elasticity and flexibility. So that it seems logical to see the maximum-stress-concentration in the place of deformation and bending of the polyamide base. However, in the base of CCRPD, such deformations did not occur in the structure of the prosthesis. So that the stress level was maximum at the place where the force was applied, and as moving toward the sides of the force-applied-place and to the posterior of the base, the amounts of stress were decreased.

The aim of this study was to investigate the "stress" applied on edentulous ridges. The PA bases can be distorted as the result of applied forces and can transfer these forces to their underlying tissues. According to the elastic nature of PA materials, stress will be released extensively. In addition, if the RPD base is wide, the force applied per unit area (i.e. stress) will be very little. For this reason, in our study, the amounts of stresses transmitted to the edentulous ridge by PRPD was much smaller than those transmitted by CCRPD. So that, despite the differences in the results of "force" and "stress", both were consistent.

Like any other FEM studies, there were some limitations in the current study. So that it is not simple to overgeneralize the results of any FEM studies to the real-clinical-patients without cautious. For example, the models were not exactly identical. In order to simulate the real-clinical-conditions as much as possible, two casts and two models were fabricated (i.e. one cast and one model with "rests" for CCRPD and the other cast and model for PRPD with "no rests"). If one cast and model were fabricated for both RPDs, the main problem was that the results could have not been comparable with the clinical situations. Methods and materials of that study would have been easier, but it could have not been overgeneralized to the clinical situations at all.

In this study, in contrast to the textbooks of RPDs which advised to use "lingual bar", the selected major connector for CCRPD was "lingual plate". Because lingual plate should be used as the major connector for PRPDs. So that for making two models as similar as possible, in both RPDs lingual plates were selected.

Another limitation was that because of simplicity some interfering parameters are eliminated. If not, it would be too difficult to interpret the results. For example the mandible was considered constant and not moving.

It is recommended to investigate different Kennedy Classifications of RPDs fabricated with different materials using 3D FEM. It is also recommended to explain the stresses in various parts of these RPDs e.g. in clasps and other minor connectors in other 3D FEM studies. Fatigue-stress-evaluation in PRPD and CCRPD seems to be another study-gap with little literature review.

Conclusion

Considering the limitations of this in-vitro study, the following conclusions were drawn; the support of PRPDs in bilateral-distal-extensions (i.e. Kennedy Class I) may mainly be provided with the edentulous tissues. However, these flexible bases did not transmit great stress to the edentulous ridges. Despite there were rests and metal-retentive-clasps in the CCRPD in the studied model, the applied stresses on the edentulous ridges were more than those in the PRPD model. The great differences in the amounts of stresses applied on the edentulous ridges in two models can be attributed to the elasticity and stress-breaking-properties of PRPD.

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Conflicts of interest

There are no conflicts of interest

References

1. Singh JP, Dhiman RK, Bedi RP, Girish SH. Flexible denture base material: A viable alternative to conventional acrylic denture base material. Contemp Clin Dent

2011; 2:313-7https://doi.org/10.4103/0976-237X.91795

2. Alwan SS, Ismail IJ. Retentive forces, tensile strength and deflection fatigue of Acetal thermoplastic clasp material in comparison with cobalt-chromium alloy. J Bagh College dent 2014; 26:59-66.https://doi.org/10.12816/0015166 Carr AB, Brown DT. McCracken's removable partial prosthodontics. 12th Ed. Elsevier Mosby. 2011; Chap 7:114.

3. Vojdani M, Giti R. Polyamide as a Denture Base Material: A Literature Review. J Dent (Shiraz) 2015 ;16:1-9.

4. Abhay PN, Karishma S. Comparative evaluation of impact and flexural strength of four commercially available flexible denture base materials: an in vitro study. J Indian Prosthodont Soc 2013; 13:499-508. https://doi.org/10.1007/s13191-012-0203-0

5. Fueki K, Ohkubo C, Yatabe M, Arakawa I, Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin-part I: definition and indication of non-metal clasp dentures. J Prosthodont Res 2014; 58:3-10.https://doi.org/10.1016/j.jpor.2013.12.002

6. Singh K, Aeran H, Kumar N, Gupta N. Flexible thermoplastic denture base materials for aesthetical removable partial denture framework. J Clin Diagn Res 2013 ;7:2372-3.https://doi.org/10.7860/JCDR/2013/5020.3527

7. Kaira LS, Dayakara HR, Singh R. Flexible denture for partially edentulous arches-A case report. J Dentofac Sci 2012;1:39-42.

8. Kohli S, Bhatia S. Polyamides in dentistry. Int J of Scientific Study 2013 ;1:20-5.

9. . Sharma A, Shashidhara HS. A review: Flexible removable partial dentures. J Dent Med Sci 2014 ;13:58-62.https://doi.org/10.9790/0853-131265862

10. Ucar Y, Akova T, Aysan I. Mechanical properties of polyamide versus different PMMA denture base materials. J Prosthodont 2012 ;21:173-6.https://doi.org/10.1111/j.1532-849X.2011.00804.x

11. Zappini G, Kammann A, Wachter W. Comparison of fracture tests of denture base materials. J Prosthet Dent 2003 ;90:578-85.https://doi.org/10.1016/j.prosdent.2003.09.008

12. Hamanaka I, Takahashi Y, Shimizu H. Mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2011 ;69:75-9.https://doi.org/10.3109/00016357.2010.517557

13. Hamanaka I, Iwamoto M, Lassila L, Vallittu P, Shimizu H, Takahashi Y. Influence of water sorption on mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2014 ;72:859-65.https://doi.org/10.3109/00016357.2014.919662

14. Takahashi Y, Hamanaka I, Shimizu H. Effect of thermal shock on mechanical properties of injection-molded thermoplastic denture base resins. Acta Odontol Scand 2012 ;70:297-302.https://doi.org/10.3109/00016357.2011.600719

15. Wadachi J, Sato M, Igarashi Y. Evaluation of the rigidity of dentures made of injection-molded materials. Dent Mater J 2013 ;32:508-11.https://doi.org/10.4012/dmj.2013-061

16. Mutto JC, Sato TP, Silva JMF, Borges ALS, Uemura ES. Retentiveness comparison of individual clasps made from polyamide, acetate resin and cobalt-chrome for removable partial dentures. Brazilian Dent Sci 2019 ;v22i4:483-7.https://doi.org/10.14295/bds.2019.v22i4.1802

17. Yamamoto ETC, Sato TP, da Silva JMF, Borges ALS, Uemura ES. Retentive force comparison between esthetic and metal clasps for removable partial denture. Brazilian Dental Science. 2017;20:87-92.https://doi.org/10.14295/bds.2017.v20i3.1431

18. Sadek SHA, Dehis WM, Hassan H. Comparative Study Clarifying the Most Suitable Material to Be Used as Partial Denture Clasps. Maced J Med Sci 2018 ;6:1111-1119.https://doi.org/10.3889/oamjms.2018.226

19. Nguyen LG, Kopperud HM, Øilo M. Water sorption and solubility of polyamide denture base materials. Acta Biomater Odontol Scand 2017 ;3:47-52.https://doi.org/10.1080/23337931.2017.1326009

20. Nokar S, Bahrami M, Hajmiragha H, Aslani P. Comparative Evaluation of the Stresses Applied to the Bone, fixtures, and Abutments of Implant-Supported Fixed-Partial-Dentures with Different Long-Spans, After Cyclic Loading Using 3 Dimensional Finite-Element-Method. Int J of Recent and Innovation Trends in computing and communication 2017 ;5:122-29.

21. Nokar S, Bahrami M, Mostafavi AS. Comparative Evaluation of the Effect of Different Post and Core Materials on Stress Distribution in Radicular Dentin by Three-Dimensional Finite Element Analysis. J Dent (Tehran) 2018 ;15:69-78.

22. Phoenix RD, Cagna DR, DeFreest CF. Stewart's Clinical Removable Partial Prosthodontics. 4th Ed. Quintessence Pub, Lication Co, Inc. 2008; Chap 11: 321-322.

23. Sakaguchi RL, Powers JM. Craig's Restorative Dental Materials. 13th Ed. Mosby Elsevier. 2012; Chap 4: 34-41.

24. Fueki K, Ohkubo C, Yatabe M, Arakawa I , Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin-Part I: definition and indication of non-metal clasp dentures. J Prosthodont Res 2014;58:3-10.https://doi.org/10.1016/j.jpor.2013.12.002

25. Fueki K, Ohkubo C, Yatabe M, Arakawa I , Arita M, Ino S, et al. Clinical application of removable partial dentures using thermoplastic resin. Part II: material properties and clinical features of non-metal clasp dentures. J Prosthodont Res 2014;58:71-84.https://doi.org/10.1016/j.jpor.2014.03.002

26. Li K, Xin H, Zhao Y, Zhang Z, Wu Y. Remodeling of the Mandibular Bone Induced by Overdentures Supported by Different Numbers of Implants. J Biomech Eng 2016; 138: 051003.https://doi.org/10.1115/1.4032937

27. Zarrati S, Bahrami M, Heidari F, Kashani J. Three Dimensional Finite Element Analysis of Distal Abutment Stresses of Removable Partial Dentures with Different Retainer Designs. J Dent (Tehran) 2015 ;12:389-97.

28. Engineering ToolBox, (2008). Polymers - Physical Properties. [online] Available at: https://www.engineeringtoolbox.com/polymer-properties-d_1222.html

29. Takabayashi Y. Characteristics of denture thermoplastic resins for non-metal clasp dentures. Dent Mater J 2010 ;29:353-61.https://doi.org/10.4012/dmj.2009-114

30. Hill EE, Rubel B, Smith JB. Flexible removable partial dentures: a basic overview. Gen Dent 2014 ;62:32-6.

31. 32. Lekha K, Meshramkar R, Harsha B, Sandhaya R, Shilpa S, Vani HM. Finite Element Stress Analysis of Circumferential Clasp Using Acetal Resin and Chrome Cobalt as Clasp Material. Global J Res Analysis 2015 ;4:51-53.

32. Muraki H, Wakabayashi N, Park I, Ohyama T. Finite element contact stress analysis of the RPD abutment tooth and periodontal ligament. J Dent 2004 ;32:659-65. https://doi.org/10.1016/j.jdent.2004.07.003

33. Jiao T, Chang T, Caputo AA. Load transfer characteristics of unilateral distal extension removable partial dentures with polyacetal resin supporting components. Aust Dent J 2009 ;54:31-7.https://doi.org/10.1111/j.1834-7819.2008.01085.x