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Stress and strain analyses of removable partial denture abutment tooth in relation to the position of the minor connector

Анализа напона и деформација унутар ретенционог зуба парцијалне скелетиране протезе у зависности од угла са малом спојницом

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SUMMARY

Introduction/Objective For optimum loading distribution angle formed by the occlusal rest and the vertical minor connector from which it originates should be less than 90 degrees.

The objective of the article was to visualise the optimum angle between the occlusal rest and the minor connector in terms of intensity and distribution of occlusal loads using finite elements analysis. It was the intention, concerning biomechanical behavior, to document that optimum angle between the occlusal rest and the minor connector should be less than 90 degrees.

Methods Three different virtual models of partial edentulous Kennedy III class were created using the CATIA design computer program with different angles between the occlusal rest and the minor connector. Stress distribution after simulated occlusal loading was analysed using finite element method.

Results Comparing the results obtained for three models, the highest stress values were seen in model 3 (the angle between occlusal rest and small conector is higher than 90 degrees) whether the load is applied in the middle or the end of the saddle.

Conclusion Within limitations and on the basis of the study results, the minimum compressive stress was seen in model 1 where the angle between the occlusal rest and the minor connector was less than 90 degrees whether the load is applied in the middle or the end of the saddle. It is recommended that obtuse angle between the rest and minor connector may be avoided due to potential hazardous stress concentration on abutment teeth.

Keywords: minor connector; occlusal rest; finite element analysis; stress and strain

САЖЕТАК

Увод/Циљ Оклузални наслон и мала спојница требају да заклапају међусобни угао мањи од 90 степени, како би се обезбедило најповољније преношење оптерећења.

Циљ рада је био да се методом коначних елемената прикаже оптималан угао између оклузалног наслона и мале спојнице који је најповољнији за преношење оклузалног оптерећења. Намера је била да се посматрано са биомеханичког аспекта документује да је угао мањи од 90 степени између оклузалног наслона и мале спојнице најповољнији.

Метод Израђена су три различита виртуелна модела крезубе вилице класе крезубости Кенеди III у програму *CATIA* са моделованим разичитим угловима између оклузалног наслона и мале спојнице. Анализа дистрибуције напона и деформација након симулираног оклузалног оптерећења је извршена методом коначних елемената.

Резултати После симулираног оклузалног оптерећења сва три модела, највећи напон је уочен код модела 3 (угао између оклузалног наслона и мале спојнице већи од 90 степена), без обзира да ли је оптерећење апликовано на средини или на крају седла.

Закључак У оквиру ограничења у истраживању, најмањи компресиони напон уочен је у моделу 1 (угао између оклузалног наслона и мале спојнице мањи од 90 степени) без обзира да ли је оптерећење апликовано на средини или на крају седла. Препоручује се да се туп угао између оклуазног наслона и мале спојнице избегава због могућих штетних концентрација напона на ретенционом зубу.

Кључне речи: мала спојница; оклузални наслон; метода коначних елемената; напон и деформације

INTRODUCTION

A tooth as a part of orofacial system is subjected to great occlusal loads during normal function. As a result of occlusal loading reactionary stresses are generated and distributed throughout whole tooth structure. The same is factual for a tooth acting as an abutment tooth of a removable partial denture (RPD), where most occlusal forces are distributed from the occlusal rest to the abutment. Teeth and their supporting tissues are best suited for resisting axially directed forces. [1] When not loaded paralel to the long axis, such forces may generate stresses and strains in the tooth and PDL, causing various problems such as extreme tooth movement, non-carious cervical lesions formation, and cervical alveolar bone loss [2, 3] Occlusal loads exerted on an RPD are transmitted to abutment teeth and oral mucosa, respectively. Therefore, when planning RPD one is facing the presence of two different biological tissues and the need for the even distribution of the occlusal and other forces on the periodontal tissue of the remaining teeth and in the mucoperiosteum on the edentulous alveolar ridge [4]. To emply the stated, the design of the RPD requires biomechanical considerations in order to minimize potential hazardous loading on supporting tissues. Therefore, each element in the RPD design should fullfil requirements concerning function and aesthetics, but also enables patient comfort and preserves supporting tissues health and well being.

A minor connector is the connecting link between the major connector of an RPD and the other units such as clasps, indirect retainers, and occlusal rests [5]. From the biomechanical perspective it possess a very important role to connect the aforementioned elements of the RPD to the major connector. In such a way it enables the RPD to act as a single unit rather than elements acting separately and individually. This way forces applied to one part of the RPD are transmitted to the other parts, and are dissipated by all teeth and supporting tissues. For optimum loading distribution angle formed by the occlusal rest and the vertical minor connector from which it originates should be less than 90 degrees. [6, 7]. Only in this way the occlusal forces can be directed along the long axis of the abutment tooth and prevents slippage of the RPD away from the abutment [7]. So far, there were no bimechanical study supporting the aforementioned statements.

The objective of this study was to visualise the optimum angle between the occlusal rest and the minor connector in terms of intensity and distribution of occlusal loads using finite elements analysis. With this aim it was the intention to document in terms of biomechanical behavior, that optimum angle between the occlusal rest and the minor connector should be less than 90 degrees.

METHODS

Three different virtual models of partial edentulous Kennedy III class were created using the CATIA design computer program. The surface geometry of all three models was obtained based on digital data obtained by scanning of the denture, teeth and jaw models. Three denture models were set up using a lower jaw models of Class III partially edentualism with tooth-borne removable partial denture. Morphologic details and dimensions were used to define a series of planes at different levels. The basic morphology outlines were reconstructed, with detailed morphological characteristics obtained from the literature [8, 9]. The teeth surfaces were reconstructed in the finite element models by fitting polynomial surfaces through geometric records. The geometric characteristics of occlusal rest seat were taken from the literature. Each rest seat was a spoon-shaped, 1.5 mm deep, occupied one-third of the mesiodistal length of the tooth, and was approximately one-half the buccolingual width of the tooth, measured from cusp tip to cusp tip [10]. The occlusal rests that were fully fitted to the corresponding rest seats were separately produced as hemisphere shapes. The following three 3D models were created for this study:

1. The first model was model of the tooth-bounded saddle where the angle between the occlusal rest and the minor connector is less than 90 degrees;
2. The second model was model of the tooth-bounded saddle where the angle between the occlusal rest and the minor connector is 90 degrees;
3. The third model was model of the tooth-bounded where the angle between the occlusal rest and the minor connector is higher than 90 degrees.

The geometric characteristic of the tooth-bounded saddle were obtained by measurements of dimensions and shapes of the saddles in the large number of the master casts. From the basic geometry created, the elastic propreties of various materials were attributed using approximate values found in the literature [11, 12] (Table 1). It was assumed that the mechanical behavior of the teeth, rests and minor connectors were linear elastic, homogeneous, and isotropic.

Table 1. Materials mechanical propreties.

Material	Young' Modulus (MPa)	Poisson's Ratio
Enamel	4.1×10^4	0.30
Dentin	1.9×10^4	0.31
Periodontal ligament	0.00689×10^4	0.45
Co-Cr alloy	23×10^4	0.33

According to literature data [12, 13] the intensity of the occlusal force is within the range of 50 N in edentulous patients to 1000 N in extreme cases of full dental arch. The values in the range 25–300 N are considered physiological for denture wearers. The occusal force intensity of 250 N in RPD wearers was found by Witter et al. [14]

For this reason, a vertical load of 250 N was applied according in two simulated situations:

In the first simulation, the load was applied in the middle of the tooth-bounded saddle in all three models.

In the second simulation, the load was distributed in the end of the tooth-bounded saddle in all three models.

Each model was meshed by structurally with solid elements defined in tetrahedral bodies. The final models had a total number of 42176 elements and 63572 nodes for model 1, 53141 elements and 77213 nodes for model 2 and 60119 elements and 80123 nodes for model 3.

Described virtual three-dimensional finite element models of the tooth-bounded saddle with different angle between the occlusal rest and the minor connector were analysed using FEA program (ANSYS 6.1, ANSYS, Canonsburg, PA, USA).

RESULTS

The results of the study are presented graphically as maps of stress distribution within the saddle and occlusal rest minor connector junction.

When a vertical load was applied at the middle of the tooth-bounded saddle, the highest maximum compressive stress was found in the saddle area at the site of applied load in model where angle angle between the occlusal rest and the minor connector was modelled less than 90 degrees (Figures 1 and 2). Under the same condition of loading, the stress intensity decreased increasing the distance from the loading site with uniform distribution throughout whole saddle. The pattern of stress distribution is the same in model 2 angle equals 90 degrees as seen in Figures 3 and 4), whereas the

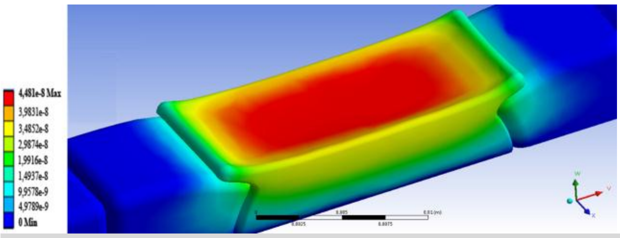

Figure 1. Stress distribution in model 1 when the load was applied in the middle of the tooth-bounded saddle.

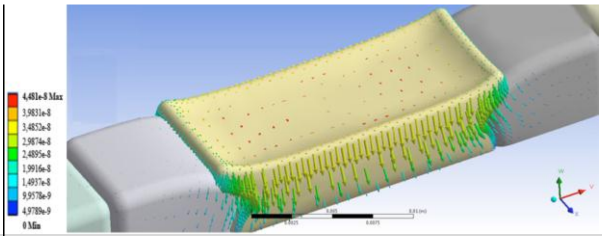

Figure 2. Schematic diagram of stress distribution in model 1 when the load was applied in the middle of the tooth-bounded saddle.

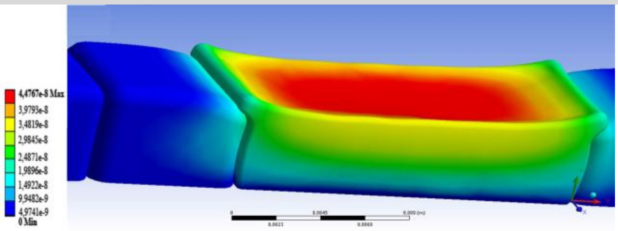

Figure 3. Stress distribution in model 2 when the load was applied in the middle of the tooth-bounded saddle.

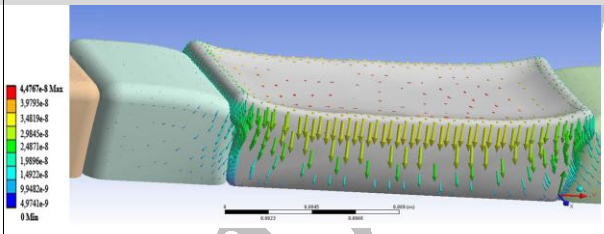

Figure 4. Schematic diagram of stress distribution in model 2 when the load was applied in the middle of the tooth-bounded saddle.

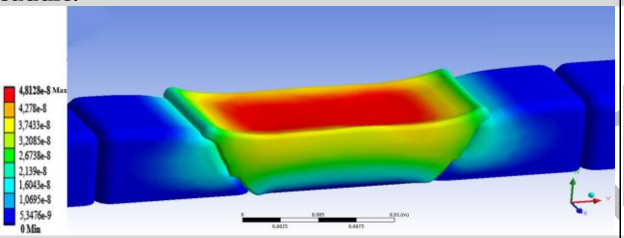

Figure 5. Stress distribution in model 3 when the load was applied in the middle of the tooth-bounded saddle.

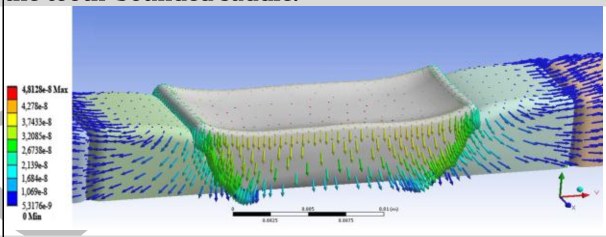

Figure 6. Schematic diagram of stress distribution in model 3 when the load was applied in the middle of the tooth-bounded saddle.

stress intensity increased. Concerning the third model with an obtuse angle between the occlusal rest and the minor connector the stress were also highest at the loading point and gradually distributed to the supporting tissues (Figures 5 and 6). Accordingly, as seen in the table 2, the highest stress values after loading in the middle of the saddle are obtained in the third model where occlual rest mnor connector angle is modelled more than 90 degrees. (Table 2).

Table 2. Maximum and mean stress values in all models when the occlusal load was applied in the middle and the end of the tooth-bounded saddle.

Models	Applied load in the middle of the saddle	Applied load in the end of the saddle
Model 1	σ_{max}=2.6 MPa σ_{mean}=1.2 MPa	σ_{max}=5.4MPa σ_{mean}=2.9MPa
Model 2	σ_{max}=2.5MPa σ_{mean}=1.2MPa	σ_{max}=6.4MPa σ_{mean}=2.4MPa
Model 3	σ_{max}=4.5 MPa σ_{mean}=2.0MPa	σ_{max}=7.7MPa σ_{mean}=3.5 MPa

When vertical load was applied at the end of the tooth-bounded saddle, the pattern of stress distribution was different to that seen in the simulated situation of loading in the middle of the saddle. The loading on one side of the saddle promotes unequal stress distribution with dominant concentration of stresses at the loading point, seen in all trhee models (Figures 7, 9 and 11). The schematic view of stress distribution in all three models under vertical loads with the point of attack in the end of the tooth-bounded saddle is shown in Figures 8, 10, 12. It

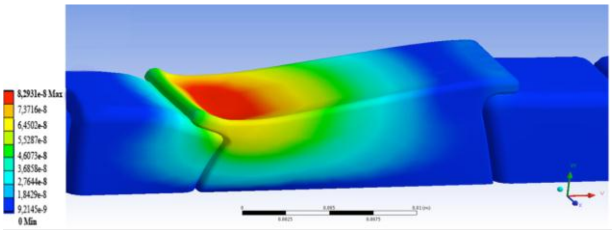

Figure 7. Stress distribution in model 1 when the load was applied in the end of the tooth-bounded saddle.

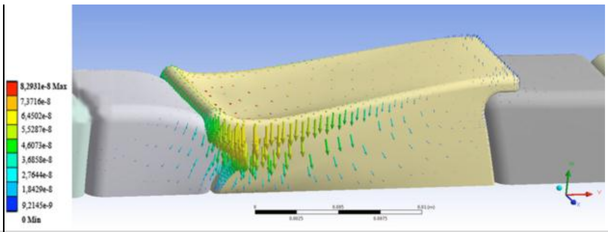

Figure 8. Schematic diagram of stress distribution in model 1 when the load was applied in the end of the tooth-bounded saddle.

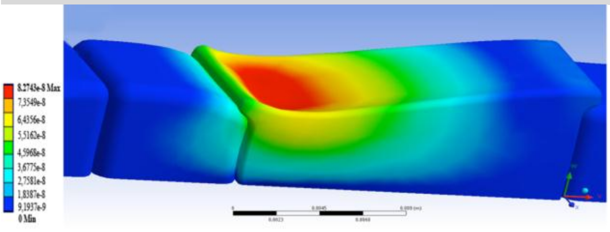

Figure 9. Stress distribution in model 2 when the load was applied in the end of the tooth-bounded saddle.

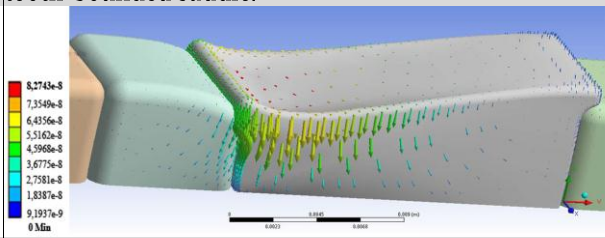

Figure 10. Schematic diagram of stress distribution in model 2 when the load was applied in the end of the tooth-bounded saddle.

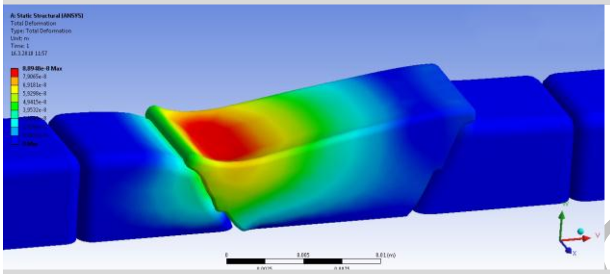

Figure 11. Stress distribution in model 3 when the load was applied in the end of the tooth-bounded saddle.

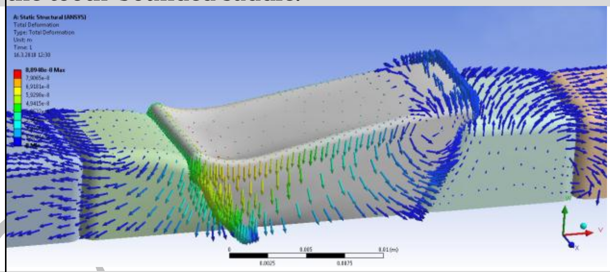

Figure 12. Schematic diagram of stress distribution in model 2 when the load was applied in the end of the tooth-bounded saddle.

is evident that there are stress concentration in the saddle structure as well as in the abutment tooth on the side of the applied load. By comparing the results obtained for three models, the highest stress values were obtained in model 3 (Table 2).

DISCUSSION

Since, the intention of the study was to visualise and document stress and strain distribution in the junction between occlusal rest and minor connector, the computer simulations were simplified. Creating the virtual models was done without intense morphological details, specially when anatomy details of the abutment tooth is concerned. Accepting the simplifications involved in the study, the values of stresses encountered during occlusal loading simulation were considered more qualitatively than quantitatively. Another limitation of this study concers regarding the intensity of occlusal force applied to the saddle and rest afterwards. The phenomenon of any horisontal movement of the rest was neglected and the RPD was assumed stable, as it is obliged to be when designed properly. Moreover, the assumed materials characteristics as isotropic, homogeneous and elastic may present the limiting factor in the study. However, despite the materials intrinsic anisotropic nature there is still no competents literature data concerning inhomogenity and anysotrpy. Since results were not considered quantitatively one may speculate that such limiting factors did not have contributing effect on the obtained data.

When simulating loading at the middle of the saddle, uniform distribution of the stresses on abutment teet and surrounding tissues is visible. On the other hand, applied loading on one side of the saddle exerted higher stresses on the abutment at that side. Accepting the forementioned it may be speculated that from the clinical perspective one is obliged to create uniform occlusal contacts in harmony to the natural dentition. Premature contacts on one side of the saddle will cause the potentially unstable leverage effects and might overload the abutment with consequtive side effects.

Evaluating the obtained results it is evident that the angle formed by the occlusal rest and the vertical minor connector from which it originates should be less than 90 degrees. The angle greater than 90 degrees fails to transmit occlusal forces along the supporting vertical axis of the abutment tooth with generated higher stresses. Also, the results of this study showed that the highest maximum compressive stress was found in the saddle area at the site of applied loads in all models. The minimum stress values were seen in model 1 where the angle between the occlusal rest and the minor conector is less than 90 degrees whether the load is applied in the middle or the end of the saddle. The findings are in agreement with previous researches [9], that horizontal axis of the occlusal rest should be inclined toward the abutment to prevent slippage of the prosthesis away from the abutment, The opposite was found by Sato et al. (2003) who stated that such inclination may cause high stress concentration. According to them, a standard-shape rest with a zero degree horizontal axis produced less stress and may prevent slippage [15]. Despite the statement that the inner line angle of an occlusal rest should be rounded [16], results of the study Sato et al. (2003) showed that overroundness was associated with high stress concentration and decreased yield strength. The authors explained that such results may be attributed to the fact that the loaded point moved to the thinnest portion (the most protruded point of occlusal rest base). Although, minority of scientific studies are dealing occlusal rest biomechanical behavior, it may be however stated that stress distribution on the residual ridge beneath the RPD base is dependent on the occlusal rest design [17],

CONCLUSIONS

Despite the deffects in models geometry and the implemented assumptions, the results still can provide some mechanical insight of the influence of the angle between the occlusal rest and the minor connector on stress distibution on supporting tissues. Within limitations and on the basis of the study results, the minimum compressive stress was seen in model 1 where the angle between the occlusal rest and the minor connector was less than 90 degrees whether the load is applied in the middle or the end of the saddle. Therefore, it may be confirmed that from the biomechanical aspect optimum angle between the occlusal rest and the minor connector should be less than 90 degrees. It is recommended that obtuse angle between the rest and minor connector may be avoided due to potential hazardous stress concentration on abutment teeth.

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