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ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

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

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SUMMARY
Introduction/Objective For optimum loading distribution, the angle formed by the occlusal rest and the vertical minor connector from which it originates should be less than 90°.
The objective of the article was to visualize the optimum angle between the occlusal rest and the minor connector in terms of intensity and distribution of occlusal loads using finite element analysis. It was the intention, concerning biomechanical behavior, to document that the optimum angle between the occlusal rest and the minor connector should be less than 90°.
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 analyzed using the finite element method.
Results Comparing the results obtained for three models, the highest stress values were seen in model 3 (the angle between the occlusal rest and the small connector is greater than 90°) whether the load is applied in the middle or at 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° whether the load is applied in the middle or at the end of the saddle. It is recommended that obtuse angle between the rest and the minor connector should be avoided due to potential hazardous stress concentration on abutment teeth.
Keywords: minor connector; occlusal rest; finite element analysis; stress and strain

INTRODUCTION

A tooth as a part of the orofacial system is subjected to great occlusal loads during normal function. As a result of occlusal loading, reactionary stresses are generated and distributed throughout the entire 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 parallel to the long axis, such forces may generate stresses and strains in the tooth and the periodontal ligament, 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. Therefore, when planning an RPD, one faces two different biological tissues and the need for 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 employ 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 fulfill requirements concerning function and esthetics, but also enables patient comfort and preserves supporting tissue 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 possesses 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. In 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° [6, 7]. Only in this way can the occlusal forces be directed along the long axis of the abutment tooth and slippage of the

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RPD away from the abutment can be prevented [7]. So far, there have been no biomechanical studies supporting the aforementioned statements.

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

METHODS

Three different virtual models of Kennedy III class partial edentulous were created using the CATIA design computer program (Dassault Systèmes, Vélizy-Villacoublay, France). The surface geometry of all three models was obtained based on digital data obtained by scanning denture, teeth, and jaw models. Three denture models were set up using lower jaw models of Class III partial edentulism with a 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 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 that of a tooth-bounded saddle where the angle between the occlusal rest and the minor connector is less than 90°;
2. The second model was that of a tooth-bounded saddle where the angle between the occlusal rest and the minor connector is 90°;
3. The third model was that of a tooth-bounded saddle where the angle between the occlusal rest and the minor connector is greater than 90°.

The geometric characteristics of the tooth-bounded saddle were obtained by measurements of dimensions and shapes of saddles in a large number of master casts. From the basic geometry created, the elastic properties 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 was linear elastic, homogeneous, and isotropic.

Table 1. Mechanical properties of the materials

Material	Young's 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, the intensity of the occlusal force is within the range from 50 N in edentulous patients to 1000 N in extreme cases of a full dental arch [12, 13]. The values in the 25–300 N range are considered physiological for denture wearers. The occlusal 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 to two simulated situations:

1. In the first simulation, the load was applied in the middle of the tooth-bounded saddle in all three models;
2. In the second simulation, the load was distributed at the end of the tooth-bounded saddle in all three models.

Each model was meshed structurally with solid elements defined in tetrahedral bodies. The final models had a total number of 42,176 elements and 63,572 nodes for model 1, 53,141 elements and 77,213 nodes for model 2, and 60,119 elements and 80,123 nodes for model 3.

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

RESULTS

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

When a vertical load was applied over 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 the model where the angle between the occlusal rest and the minor connector was modeled as less than 90° (Figures 1 and 2). Under the same condition of loading,

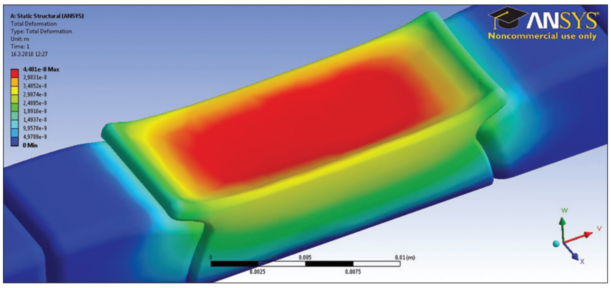

Figure 1. Stress distribution in model 1 when the load was applied in the middle of the tooth-bounded saddle

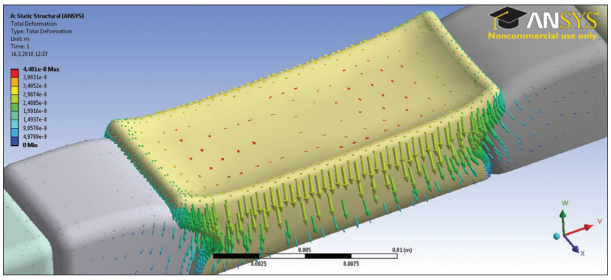

Figure 2. Schematic diagram of stress distribution in model 1 when the load was applied in the middle of the tooth-bounded saddle

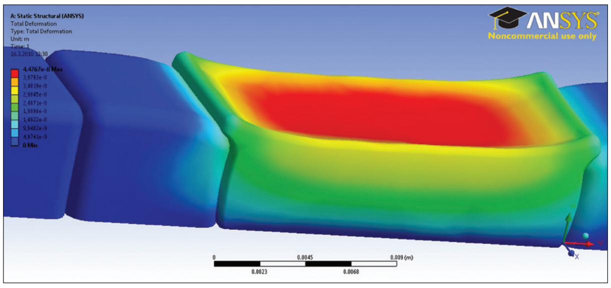

Figure 3. Stress distribution in model 2 when the load was applied in the middle of the tooth-bounded saddle

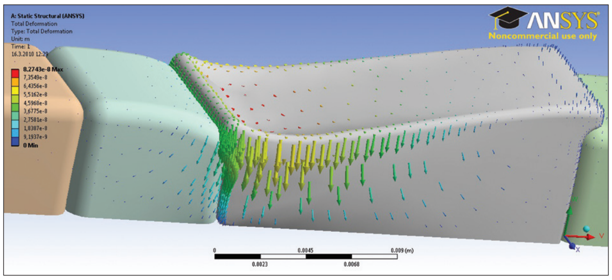

Figure 8. Schematic diagram of stress distribution in model 1 when the load was applied at the end of the tooth-bounded saddle

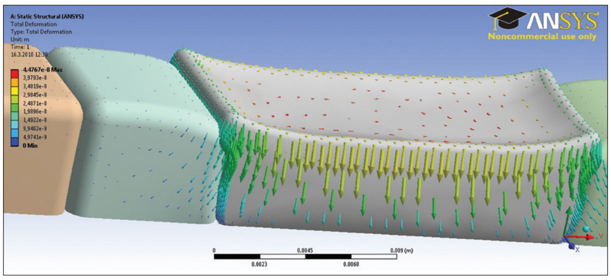

Figure 4. Schematic diagram of stress distribution in model 2 when the load was applied in the middle of the tooth-bounded saddle

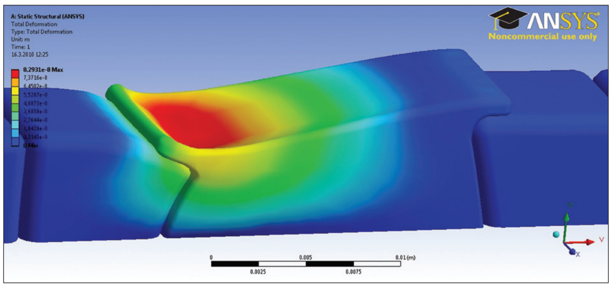

Figure 9. Stress distribution in model 2 when the load was applied at the end of the tooth-bounded saddle

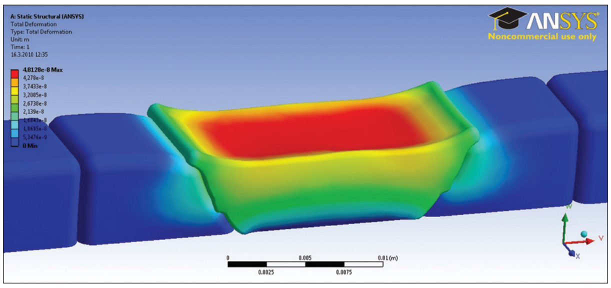

Figure 5. Stress distribution in model 3 when the load was applied in the middle of the tooth-bounded saddle

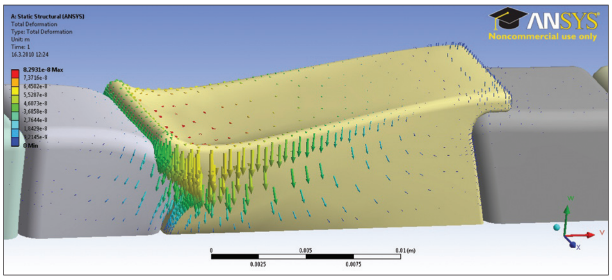

Figure 10. Schematic diagram of stress distribution in model 2 when the load was applied at the end of the tooth-bounded saddle

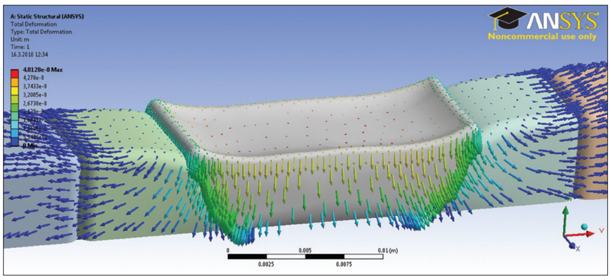

Figure 6. Schematic diagram of stress distribution in model 3 when the load was applied in the middle of the tooth-bounded saddle

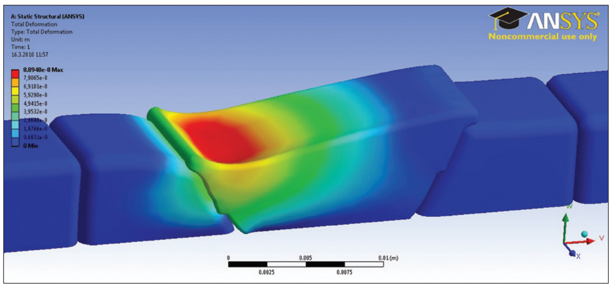

Figure 11. Stress distribution in model 3 when the load was applied at the end of the tooth-bounded saddle

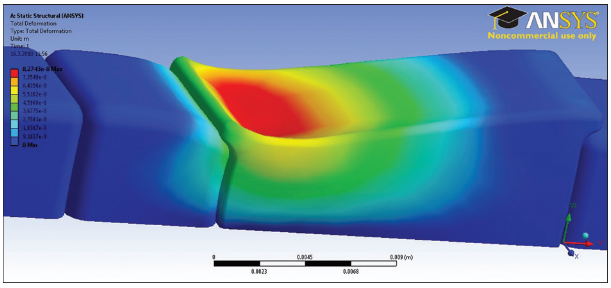

Figure 7. Stress distribution in model 1 when the load was applied at the end of the tooth-bounded saddle

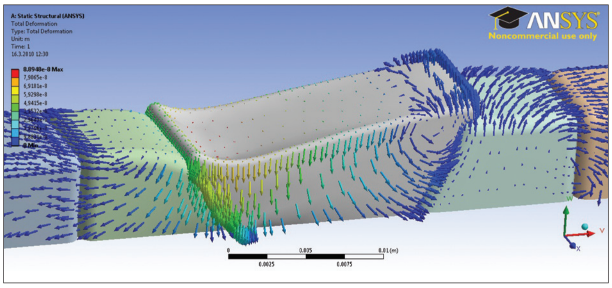

Figure 12. Schematic diagram of stress distribution in model 2 when the load was applied at the end of the tooth-bounded saddle

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

the stress intensity decreased increasing the distance from the loading site with a uniform distribution throughout the whole saddle. The pattern of stress distribution is the same in model 2 – the angle equals 90° as seen in Figures 3 and 4), whereas the stress intensity increases. Concerning the third model with an obtuse angle between the occlusal rest and the minor connector, the stress was also the highest at the loading point and gradually distributed to the supporting tissues (Figures 5 and 6). Accordingly, as seen in Table 2, the highest stress values after loading the middle of the saddle are obtained in the third model, where the occlusal rest minor connector angle is modeled as greater than 90° (Table 2).

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 the dominant concentration of stresses at the loading point, seen in all three models (Figures 7, 9, and 11). The schematic view of stress distribution in all three models under vertical loads with the point of attack at the end of the tooth-bounded saddle is shown in Figures 8, 10, and 12. It is evident that there is a 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 visualize and document stress and strain distribution in the junction between the occlusal rest and the minor connector, the computer simulations were simplified. Creating the virtual models was done without intense morphological details, especially when anatomy details of the abutment tooth are 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 concerns the intensity of occlusal force applied to the saddle and the rest afterward. The phenomenon of any horizontal movement of the rest was neglected and the RPD was assumed stable, as it is obliged to be when designed properly. Moreover, the assumed isotropic, homogeneous, and elastic characteristics of the materials may present the limiting factor in the study. However, despite the materials' intrinsic anisotropic nature, there is still no competent literature data concerning inhomogeneity and anisotropy. Since results were not considered quantitatively, one may speculate that such limiting factors did not have a contributing effect on the obtained data.

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

After 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°. The angle greater than 90° 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 connector is less than 90° whether the load is applied in the middle or at the end of the saddle. The findings that horizontal axis of the occlusal rest should be inclined toward the abutment to prevent slippage of the prosthesis away from the abutment are in agreement with previous researches [9]. The opposite was found by Sato et al. [15], who stated that such inclination may cause a high-stress concentration. According to them, a standard-shape rest with a zero degree horizontal axis produced less stress and may prevent slippage. Despite the statement that the inner line angle of an occlusal rest should be rounded [16], results of the study by Sato et al. [15] showed that over-roundness was associated with the 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 with the 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].

CONCLUSION

Despite the defects in the model 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 distribution 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° whether the load was applied in the middle or the end of the saddle. Therefore, it may be confirmed that, from the biomechanical aspect, the optimum angle between the occlusal rest and the minor connector should be less than 90°. It is recommended that an obtuse angle between the rest and the minor connector is avoided due to potential hazardous stress concentration on abutment teeth.

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

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САЖЕТАК

Увод/Циљ Оклузални наслон и мала спојница треба 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 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 различитим угловима између оклузалног наслона и мале спојнице. Анализа дистрибуције напона и деформација након симулираног оклузалног оптерећења извршене су 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 степени), без обзира на то да ли је оптерећење априковано 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 на то да ли је оптерећење априковано на средини или на крају седла. Препоручује се да се туп угао између оклузалног 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