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Free-end saddle length influence on stress level in unilateral complex partial denture abutment teeth and retention elements

Uticaj promene dužine slobodnog sedla na promenu napona retencionih zuba i spoja jednostrane kompleksne parcijalne proteze

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Abstract

Background/Aim. Different types of dental restorations are used for the therapy of unilateral free-end saddle edentulism. Unilateral complex partial denture is one of the indications for the Kennedy class II partial edentulism. The abscence of major connector and denture plate is an advantage compared to the conventional restorations, because of better comfort and shorter period of adaptation. The aim of the study was to analyse the influence of free-end saddle length change on the behaviour of unilateral complex partial denture supporting structures. **Methods.** Stress levels of the canine and the first premolar as retentional teeth and the attachments were tested under the influence of physiological forces with the loading point shifting distally in relation to the saddle length change. A virtual real size 3D model of the fixed part of the restoration (the canine and the first premolar with milled crowns) was created using the CATIA computer program. It was connected to the mobile part of partial denture with the SD snap in latch attachment. Mobile part of the restoration was designed in the region of 2, 3 and 4 lateral teeth (second premolar, first, second and third molar). By using the finite element method (FEM) stress levels analysis was performed under the load of physiological forces of 150 N in the free-end saddle teeth zone. **Results.** The results of analysis show that physiological forces cause a different stress distribution on the abutment teeth and the attachment, depending on the saddle length. **Conclusion.** The stress level values obtained for the abutment teeth as well as the attachment are far lower than the marginal ones. The behaviour of the system changes under this defined stress, but no plastic deformation occurs.

Key words:
denture, partial; dental abutments; computer simulation.

Apstrakt

Uvod/Cilj. U terapiji jednostrano slobodnog sedla koriste se različiti oblici zubnih nadoknada. Jednostrana kompleksna parcijalna proteza (JKPP) jedna je od indikacija za bezubost klase Kenedi II. Odsustvo velike spojnice i protezne ploče predstavlja prednost u odnosu na konvencionalne nadoknade zbog boljeg komfora i kraćeg perioda adaptacije. Cilj rada bio je analiza uticaja promene dužine slobodnog sedla na ponašanje potpornih struktura JKPP. **Metode.** Ispitivani su naponi očnjaka i prvog premolara kao retencionih zuba i veze (spoja) pod dejstvom fizioloških sila sa pomeranjem tačke opterećenja distalno, u zavisnosti od dužine sedla. Primenom kompjuterskog programa CATIA u realnoj veličini urađen je virtulni 3D model fiksnog dela nadoknade (očnjak i prvi premolar sa namenskim krunama) koji je veza SD *snap in latch* priključena na mobilni deo parcijalne proteze. Mobilni deo nadoknade postavljen je u predelu dva, tri, odnosno četiri bočna zuba (drugi premolar, prvi, drugi i treći molar). Primenom metode konačnih elemenata obavljena je analiza naponskih stanja pri opterećenju fiziološkim silama od 150 N u predelu zuba slobodnog sedla. **Rezultati.** Analiza proračuna pokazala je da pod dejstvom fizioloških sila dolazi do različite raspodele napona na retencione zube i spoj u zavisnosti od dužine sedla. **Zaključak.** Dobijene vrednosti za napone kako na retencionim zubima, tako i na spoju, daleko su manje od graničnih. Pri zadatim naponima dolazi do promene ponašanja, ali ne i do plastične deformacije sistema.

Ključne reči:
zubna proteza, parcijalna; zub, nosač proteze; simulacije, kompjuterske.

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Introduction

Unilateral partial edentulism, present in 1/3 of partially edentulous patients, represents a major challenge to any practitioner. For these cases implant placement is a therapy of choice. If this type of therapy is not possible for any reason, combined complex restorations can be a good alternative. Unilateral complex partial denture (UCPD) is located unilaterally and it is a combination of fixed and mobile restorations which are connected with a special type of extra coronal attachment, whose purpose is to provide retention, stability, denture guidance and axial force transfer on supporting tissues, stated by Ozcelik and Yilmaz [1] and Sherring-Lucas and Martin [2]. Primary part of an attachment is integrated in a milled crown on the abutment tooth, and the secondary part, which is in the unilateral saddle, creates the latch type connection of the whole restoration. Stamenković [3], Phoenix et al. [4] and Henderson and Steffel [5] consider this type of therapy as a restoration with high functional, esthetic and prophylactic values.

With a digital model design it becomes possible to analyze and predict the behavior of supporting tissues and the denture in function. The finite element method (FEM) represents a computerized, mathematically orientated technique. Its purpose is to obtain approximate numeric results of differential equations which describe and predict the behavior of physical systems exposed to different external influences.

FEM is used for the analysis in numerous studies in various areas of dentistry. This unique analysis is irreplaceable for complex geometry of teeth, dentures and restorations, their relationship, as well as for a large number of different materials. All of this complicates finding of analytical solution for stress and deformation values. The use of FEM in dentistry is also important because *in vivo* measuring of restoration or implant loading is very complex, and patients and ethical committees rarely approve it. That is the reason to conduct this testing *in vitro*. The aim of the research was to analyze the influence of free-end saddle length change on stress levels of UCPD abutment teeth and attachments.

Methods

In this study 3 virtual models of the Kennedy class II partially edentulous jaw were designed using the CATIA design computer program with the same abutment teeth – the canine and the first premolar, and the length of the saddle vary from model to model: model 1 – free-end saddle in the area of the second premolar, first, second and third molar; model 2 – free-end saddle in the area of the second premolar, first and second molar; model 3 – free-end saddle in the area of the second premolar and first molar; Virtual model of fixed part of the restoration with appropriate supporting structures (abutment teeth with milled crowns, alveolus, periodontal space); virtual model of the ”SD snap-in-latch” attachment; virtual model of the mobile part is designed as the simulated metal base cowered with acrylate with the number of missing teeth depending on the free-end saddle length.

The components mentioned above are combined to create the real size system for analysis (1 : 1 proportion) compared to natural teeth. The average teeth dimensions were selected to validate the results [6] (Figure 1).

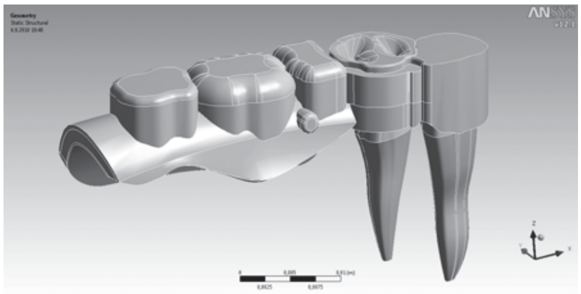

Fig. 1 – A virtual model of complex partial denture.

In order to define a virtual model of the whole system, the average distance between the enamel cementum junction and the crest of the alveolar bone of 2 mm was used, and this is how the length of the root in the bone was specified.

Virtual model analysis of UCPD was performed by using the FEM in the ANSYS Workbench 12 computer package. Stress and deformation analysis of the loaded model of UCPD, using FEM, implies finite elements net forming on a structural model. In this way, a design model is formed.

The net of adequate density is formed for a design model of unilateral complex denture, meaning: model 1 – net of 3320295 nodes and 2179811 elements; model 2 – net of 2433361 nodes and 1681724 elements, and model 3 – net of 2429373 nodes and 1581378 elements.

The 3D 10-nod tetrahedral type of finite elements (the option of 20 nodal, so-called Brick element) was used. Four types of finite elements were used in the model design: SOLID 187, Conta 174, Targe 170 and Surf 154.

All the parameters of the material used in the design process have isotropic properties. Each material has the elastic properties which are usually depicted through elastic modulus, in the field of elastic material behavior (Table 1).

Table 1

Material mechanical characteristics

Material	Young's modulus of elasticity (MPa)	Poisson's ratio	Author
Enamel	4.1×10^4	0.30	Rubin et al. [7]
Dentin	1.9×10^4	0.31	Rubin et al. [7]
Cementum	1.37×10^4	0.35	Peters et al. [8]
Pulp	0.000207×10^4	0.45	Rubin et al. [7]
Periodontal ligament	0.00689×10^4	0.45	Reinhardt et al. [9]
Alveolar bone	0.137×10^4	0.30	Güngor et al. [10]
Co-Cr-Mo	23×10^4	0.33	Stamenković [3]
Ceramics	6.9×10^4	0.33	Anusavice [11]

The elastic support unit was used for analysis to simulate the resilience of gum underneath the saddle. When a model is loaded, this base allows certain vertical movement of the saddle, and after that it starts behaving like a solid support. The resilient behavior of the gingiva is, in this way, successfully simulated, and its deflection under pressure allows certain movement of the denture. In this case the value of the elastic coefficient (elastic constant) is 750 N/mm^3, and it was set by comparing the stress values with the model on which the gingiva was created under the saddle during calculation [12]. During analysis the average tooth intrusion of 20 ± 10 μm was adopted.

In order to get the most realistic view and the most accurate calculation, the stress levels as well as the denture and teeth movement were analyzed under the load of the same biting forces at the same points on the model by transferring the applied force into pressure (according to the formula $p = F/S$, where S stands for the area of the tooth on which the force is applied).

The 150 N reference force was used for loading. On model 1, the individual teeth models, the second premolar, first, second and third molar, in the saddle were loaded. The stress level was monitored on the virtual teeth model. On model 2 the individual teeth models, the second premolar, first and second molar, in the saddle were loaded. The stress level was monitored on the virtual teeth model. On model 3, the individual teeth models, the second premolar and first molar, in the saddle were loaded. The stress level was monitored on the virtual teeth model.

Results

Calculations with preplanned model loading of the unilateral complex Kennedy class II denture were performed using the FEM. The model loading of UCPD was performed on the virtual model of the occlusal surfaces of the free-end saddle artificial teeth. Calculations were performed under the pressure of 150 N force on each free-end saddle tooth, depending on the type of model. The values of the maximal stress for the whole model, for the abutment teeth area and for the attachments area were obtained.

The results of maximal stress for the abutment teeth and the attachments of model 1 for 150 N force applied are shown in Table 2.

The results of maximal stress for the abutment teeth and the attachments of model 2 for 150 N force applied are shown in Table 3.

The results of maximal stress for the abutment teeth and the attachments of model 3 or 150 N force applied are shown in Table 4.

By analyzing all the 3 tables it becomes obvious that the distal shift of the load point results in stress level rise in all the 3 models. When 150 N force is applied on the free-end saddle teeth, maximal stress on the attachment is rising as the focus of the force shifts mesially, which indicates that the attachment absorbs the pressure, therefore providing protection to the abutment teeth.

The comparative graphs of stress level changes on the canine are shown in case when the force acts on the second premolar (Figure 2) and on the first molar (Figure 3). The comparative graphs of stress level changes on the first premolar are shown in case when the force acts on the second premolar (Figure 4) and on the first molar (Figure 5). Figure 6 shows a comparative graph of stress level changes on the abutments depending on the load point. The comparative graphs of stress level changes on the attachment in case when the force acts on the second premolar (Figure 7) and on the first molar (Figure 8). Finally, the comparative graph of the stress level changes on the attachment on the load point can be seen in Figure 9.

Table 2

The results of maximal stress for abutment teeth and attachments (model 1)

Load point	Canine (MPa)	First premolar (MPa)	Attachment (MPa)
Tooth 15	49.04	76.17	339.82
Tooth 16	56.41	91.75	250.63
Tooth 17	61.17	103.86	171.66
Tooth 18	64.50	110.07	160.20

Table 3

The results of maximal stress for abutment teeth and attachments (model 2)

Load point	Canine (MPa)	First premolar (MPa)	Attachment (MPa)
Tooth 15	50.22	56.64	114.67
Tooth 16	55.41	66.83	109.28
Tooth 17	63.08	80.92	115.26

Table 4

The results of maximal stress for abutment teeth and attachments (model 3)

Load point	Canine (MPa)	First premolar (MPa)	Attachment (Mpa)
Tooth 15	50.40	49.11	346.70
Tooth 16	59.22	60.87	187.18

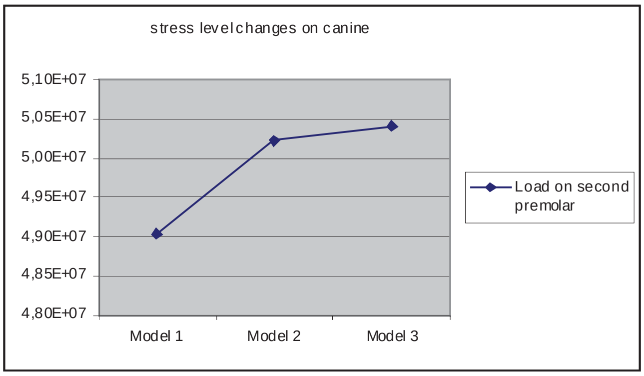

Fig. 2 – Comparative graph of stress level changes on the canine when force acts on the second premolar.

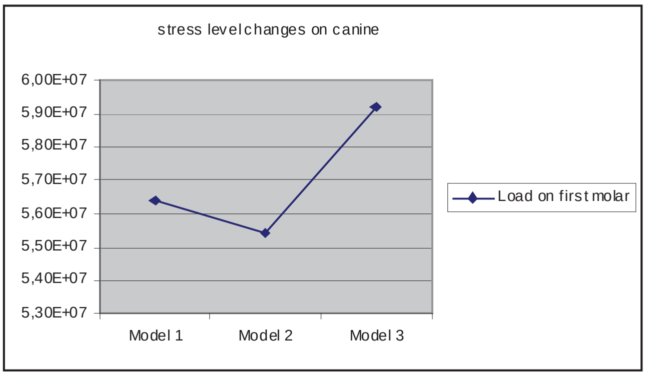

Fig. 3 – Comparative graph of stress level changes on the canine when force acts on the first molar.

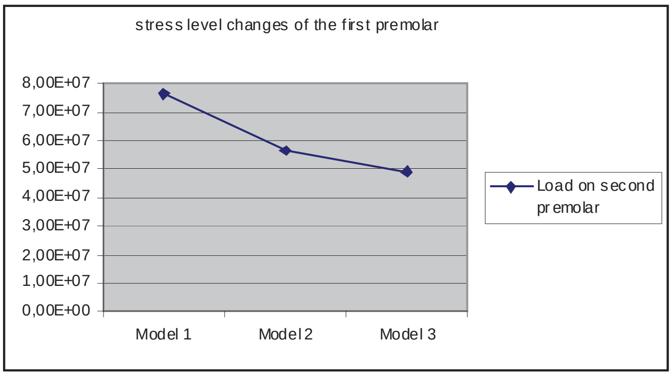

Fig. 4 – Comparative graph of stress level changes on the first premolar when force acts on the second premolar.

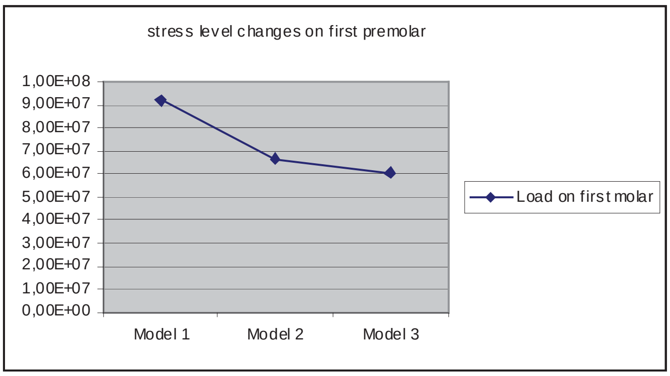

Fig. 5 – Comparative graph of stress level changes on the first premolar when force acts on the first molar.

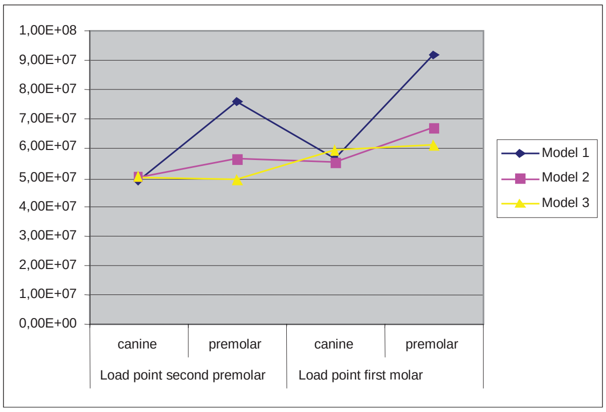

Fig. 6 – Comparative graph of stress level changes on the abutments depending on the load point.

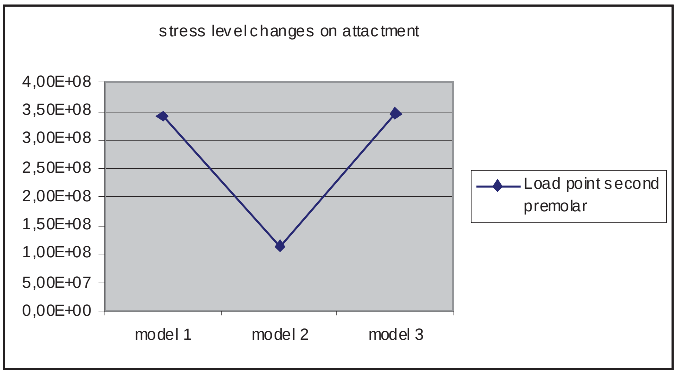

Fig. 7 – Comparative graph of stress level changes on the attachment when force acts on the second premolar.

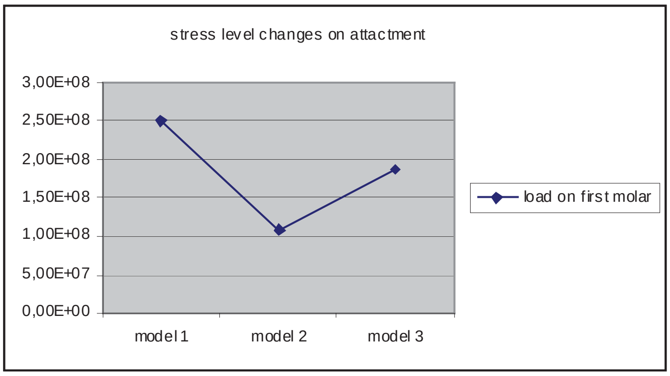

Fig. 8 – Comparative graph of stress level changes on the attachment when force acts on the first molar.

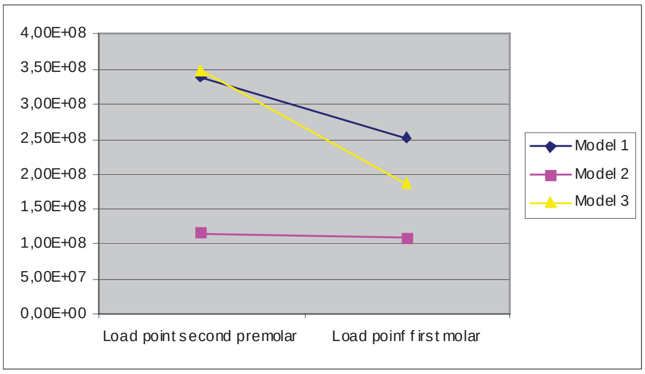

Fig. 9 – Comparative graph of stress level changes on the attachment depending on the load point.

Discussion

UCPD use in dental practice is a controversial subject. Stomatognathic structures which support removable partial denture (RPD) are histologically and anatomically made of different tissues, and therefore RPD has to match specific criteria. RPD building materials demand that all the RPD parts have to be connected, thus providing the necessary stiffness. The practitioner is faced with a problem of equal loading of two biologically different tissues. By comparing the values of mucosal resiliency of 1.5 ± 0.3 mm to the average value of teeth intrusion 20 ± 10 µm, the variable proportion appears. The best scenario is if the patient has fairly large, but still physiological axial movement of the teeth contrary to low mucoperiosteal resiliency. Edentulous jaws do not have the pressure resistant tissues. This research shows that the alveolar mucosa and gingiva can adapt to non-physiological requirements if they are adequately loaded. Periodontal tissues react best to the axially directed pressure. Actions which contribute to unilateral complex denture supporting tissues preservation are: good evaluation of the present status, adequate preparation of the supporting tissues and teeth, appropriate connection selection of the elements supported by teeth and mucosa, future denture base size defining and the restoration of the optimal occlusal relation, as stated by Radović [12].

In unilateral complex denture design, in everyday clinical practice, first and second premolars are most often used as abutment teeth. The canine and first premolar can also be an option. The reasons for this are the attachment manufacturer recommendation and the opinion that the long length saddle acts as the class 1 lever, i.e. rigid pole with a fulcrum on one side, such can damage the RPD supporting structures.

Biting forces vary ranging from minimal to maximal and they represent the reflection of muscle strength and activity. They are limited by the periodontal ligament capacity in the case of people with natural teeth, and by the mucosal sensoric capacity in mobile restoration users. In his study Trenouth [13] states that the biting force intensity ranges between 100 N and 700 N, depending on the intercanine or molar tooth region. Miyaura et al. [14] state that the biting force intensity ranges from 300 N for the patients with removable restorations, to 500 N for the intact dentition. Željković [15] states that the maximal biting force of natural dentition resembles the biting force of patients with fixed prosthetic restorations, but in case of patients with removable restoration it is reduced by 1/3 or 1/4 of its value. Pellizzer et al. [16] studied the behavior of implant supported RPD and UCPD under loads of 150 N, 210 N and 300 N, using FEM, and they concluded that the supporting structures behaved well under those loads. The results of the study by Tumrasvin et al [17] show that the maximal biting force in the upper jaw is around 240 N, and in the lower jaw 300 N, and if there are 3 missing the maximal biting force is 150 N. This is the reason to choose 150 N force to load free-end saddle teeth in this study.

The net of finite elements itself greatly influences the precision of the FEM results. The more complex the net (larger number of nodes and elements for the given model) the more precise problem solution can be expected, because the mathematical model itself resembles the real object more closely. During determination of the necessary net density it is important to bear in mind that there is a certain number of mathematical equations behind every element or nod.

Šćepanović [18] used the FEM to analyse of shape and the safety level check of the RPD retentive clasp arm, while Milić [19] used it for occlusal rest design optimization. Todorović et al. [20] and Radović [12] use the finite element simulation for unilateral complex denture load analysis and therapy possibilities. Aoda et al. [21] also used FEM in their research on unilateral complex dentures. Grbović et al. [22], Darendeliler et al. [23] and Eto et al. [24] used it for the simulation of UCPD behavior under load.

Regularity is found in the effect of 150 N force on the models 1, 2 and 3 free-end saddle teeth. As the load point shifts distally, stress level is rising on the abutment teeth. The explanation for this result lies in the fact that the lengthening of the lever arm results in the stress level rise. The potential solution for this kind of stress level rise is the maximal extension of the denture saddle, directed to reducing the force per unit area. This result is not in accordance with the results of the study by Radović et al. [25]. They found that the stress levels of the model and the abutment teeth decline with the rise of force intensity and distal shift of the load point. The reason for this can be found in the fact that, during this study, the loading force used was considerably lower, resulting in the different behavior of the model and different stress distribution.

UCPD can be considered as a suspended solid structure, as stated by Željković [15], or rigid as stated by Saito et al. [26] in their study. Considering this fact, the change in stress level on the models could be explained with the class 1 lever analysis.

The research shows that the primary abutment tooth, the first premolar, is least loaded in the model 3. This result can be explained by the fact that in this case lever arm is the shortest and the abutment tooth is close to the load point. Contrary to this, the first premolar takes the highest load, regardless the load point, in the model 1. The reason for that is the longer lever arm compared to the other two models. Secondary abutment tooth – canine, takes the highest load in case of the model 3 action force, because here the lever arm is longer than in case of the first premolar, i.e. abutment tooth is further from the load point. The highest tension was found when the force acts on the first molar, and the reason for that is the fact that the length of the lever arms in this case is highest.

Since the second premolar and the first molar were present in the free-end saddle of all the 3 models, the results were compared.

When force acts on the second premolar or the first molar, the loading of the secondary abutment – canine, does not change much with the change in the saddle length. Regularity was found that when the saddle is shortest, the loading of the first abutment is largest. This result can be explained by reduced, i.e. minimal saddle extension compared with the other two models, so the chewing pressure is in this case transferred dentally to the fullest extent.

By observing the stress distribution on the primary abutment – first premolar, we can see the trend of load decline with the decline of the saddle length, no matter if the load point is positioned on the second premolar or the first molar.

By comparing the models 1, 2 and 3 we can see that the stress level on the first premolar is always higher than the stress level on the canine, which confirms the results of Saito et al. [26]. They found that in case of unilateral removable partial denture retained with attachment, the stress was largely concentrated on the first premolar.

When we compare stress distribution on the attachment, when force acts on the second premolar and the first molar, we can see that the attachment tension is minimal in the model 2, which confirmes that this model is best constructed for the attachment. Worst conditions were found when the load point was on the second premolar on the model with the shortest saddle (model 3). The reason for this result lies in the fact that in this case the load point of the force is very close to the attachment, and the saddle is least extended. The attachment here accepts most of the load and protects both abutments. Although the conditions are unfavorable, these values are under the marginal ones for plastic deformation of the attachment. Very similar situation can be found in the model 1, when the load point is located on the second premolar. Here, the attachment also accepts most of the load, therefore protecting the canine.

Regularity was detected in case when the load point is on a distally positioned tooth, the attachment is less strained. In such conditions the load is more evenly dispersed. This result is in correlation with the study by Todorović et al. [20]. They also conclude that with a distancing load point the stress level on the attachment reduces.

By observing the stress levels in the model 2, we can see the optimal distribution of stress on the abutment teeth, as well as on the attachment, regardless the load point. With the change in saddle length a significant tension of attachment and/or teeth is observed.

Regularity in stress distribution found on the abutment teeth of the models 1 and 3 was also detected. Namely, on the model with the longest saddle, the model 1, the tension on the canine was minimal, regardless the load point position, and the largest part of the load was transferred on the attachment. On the same model we can see the significant tension on the premolar. But still, the attachment accepts most of the loading, therefore protecting the abutment teeth.

Contrary to that, in the model 3, we can see higher tension of the canine than premolar regardless the action force position. Here we can also see the regularity, same as the one in the model 1, where the attachment accepts most of the loading. These results are in accordance with the study of Todorović et al. [20]. They find that when the abutment teeth are exposed to high stress levels, the attachment accepts the stress, therefore protecting the abutment teeth.

Conclusion

This study shows that it is possible to analyze an UCPD with numerical methods. By loading the model of UCPD and by observing the stress distribution for the whole model and for its separate parts we can conclude that models with 2 or 3 teeth in the free-end saddle do not show significant changes in stress levels of abutment teeth with the shift of the load point. A model with 4 teeth in the free-end saddle, shows a significant oscillation depending on the action force position. Also, when the load point is on the second premolar and the first molar, the model with the longest saddle shows the highest stress levels on the primary abutment. It should be noted that the third molar in a free-end saddle is contraindicated in a standard clinical practice and it was created as a part of the virtual model in order to provide adequate analysis of stress distribution in the exsperimental conditions. The stress levels of the abutments of the other two models are similar, under the same loading.

Stress levels found both on abutment teeth and on the attachment are far lower than the marginal ones. Under the preformed stress the system behavior changes, but the plastic deformation of the system does not occur.

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