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Strain visualization of supporting tissues rehabilitated using two different types of removable partial dentures

Визуелизација деформација у потпорним ткивима рехабилитованим са два различита типа парцијалних скелетираних протеза

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SUMMARY

Introduction/Objective Current biomechanical analyses can provide full view of strain induced by loading of various replacements to be used for prosthetic rehabilitation.

The aim of this study was to analyze strain distribution of supporting tissues beneath two different types of the removable partial dentures, commonly indicated in the conventional rehabilitation of the partially edentulous patients.

Methods This *in vitro* study included two groups of experimental models composed of the mandibles (Kennedy Class 1) and two types of removable partial dentures. These models were exposed to occlusal loading and the digital image correlation method was used for strain visualization and strain measurement.

Results The highest strain was measured beneath the removable partial dentures, on the surfaces of bone adjacent to distal abutments and in the anatomical structure so-called the retromolar area. Strain values in the experimental models with clasp removable partial dentures were ranged from 0 to 10 %. Strain values in the experimental models with attachment-removable partial dentures were ranged from 0 to 2.3 %.

Conclusion The findings provided that attachment retained removable partial dentures induced lower strain in the residual alveolar ridges. However, higher strain was detected in the marginal bone next to the abutment teeth.

Keywords: Partially edentulous mandible; Digital image correlation method; Removable partial denture; Bone strain

САЖЕТАК

Увод/Циљ Савремене биомеханичке анализе омогућавају комплетну визуелизацију деформација од оптерећења различитих зубних надокнада у протетској рехабилитацији.

Циљ ове студије је био анализа дистрибуције деформација унутар потпорних ткива испод два различита типа најчешће коришћених парцијалних скелетираних протеза.

Метода *In vitro* студија је обухватила две групе експерименталних модела доњих вилица (Кенеди I класа крезубости) и два типа парцијалних скелетираних протеза. Моделу су били изложени оклузалним силама, а за приказ и мерење деформација је коришћена метода дигиталне корелације слика.

Резултати Највећа деформација је измерена испод парцијалних протеза, на површинама кости која окружује дисталне зубе носаче и у ретромоларној регији. Вредности деформација у експерименталним моделима са протезама ретинираним ливеним кукицама су биле 0–10%. Вредности деформација у експерименталним моделима са протезама ретинираним атечменима су биле 0–2,3%.

Закључак Парцијалне скелетирание протезе са атечменима индуковале су мање деформације резидуалног алвеоларног гребена. Веће деформације су уочене у маргиналној кости која је у непосредном контакту са зубима носачима.

Кључне речи крезубе доње вилице; метода дигиталне корелације слика; парцијална скелетираниа протеза; деформација кости

INTRODUCTION

The success or failure of prosthetic treatment of patients rehabilitated with removable partial denture (RPD) depends on the oral health state, the preparation designs on the available tooth structure and the long-term prognosis of remaining teeth [1]. Additionally, the RPD-framework design, the clasp morphology and the extension of the RPD saddles, as well as adequately established guiding planes, properly prepared rest seats and perfectly-designed, milled crowns have a significant effect on ensuring a predictable and favorable prognosis for the treatment with removable partial dentures (RPDs) [2–4]. Important factors like careful planning, designing, and preparations of remaining teeth are essential, since adequately prepared rest seats and precisely fitting rests will provide mutual assistance between teeth and RPD in order to support each other [3, 4]. The design requirements must be especially considered in order to achieve proper and uniform occlusal load

distribution. Properly balanced and transferred occlusal loads, improve longevity of remaining teeth, bone and prosthesis made to replace missing oral structures. Therefore, well sophisticated RPD design manufactured in that manner in correlation with properly prepared abutments fulfil the functional, prophylactic and aesthetic demands placed upon it.

Although significant explanations about the biomechanical behavior of RPDs were proposed in the last few decades the knowledge about ideal design isn't clear enough [2–6]. Some numerical and photoelastic models [5–7] and *in vivo* analyses [3, 8] estimated and showed RPD displacement under occlusal loading. Practically methods for biomechanical investigation of biomaterials and jaw bone are based on either contact or non-contact mechanism for strain/displacement measurement [9-18].

The aim of the following study was to determine and evaluate biomechanical behaviour as the function of strain in the supporting tissues beneath two different types of the RPD most commonly used in the conventional rehabilitation of partially edentulous patients. The study employed the Digital Image Correlation technique for the strain determination. Following the aim of this study, the role of this study was to explain the effects of the strain produced by vertically loaded RPD replacements on supporting dental tissue. A region of interest was considered to be a surface that surrounded RPDs and distal retainers/abutments. In order to facilitate the interpretation of the results we divided region of interest into two locations (segments): the anterior one (AS), corresponds to supporting bone tissue adjacent abutment; and the posterior segment (PS), corresponds to the retromolar area.

Three sets of null hypothesis were established prior to statistical analysis: 1) Mean strain values are the same for all models; 2) Mean strain values are the same for both segments (AS, PS); 3) There is no interaction in effect, between prostheses and segments of interest.

METHODS

A total number of 6 dried, partially edentulous mandibles (two groups of three models) with bilaterally shortened dental arches (Kennedy Class 1) with first premolars remained ($8 \leq n \leq 10$; N=number of the remaining teeth) was used in the experiment: three mandible were restored with clasp retained removable partial dentures (cRPDs) and another 3 mandible were restored with attachment retained removable partial dentures (aRPDs). The mandibles were borrowed from the Laboratory for Anthropology of Institute of Anatomy of Faculty of Medicine in Belgrade, Serbia. The donors were men, in the late sixties. The mandibles were checked to exclude any damages. The chosen mandibles were immersed in the 0,9 % NaCl for 8 hours to reach the volume and elasticity as much as possible [12]. Following the drying procedure (27°C), the remaining teeth were prepared to receive metal ceramic restorations. Coarse and fine diamond burs were used during preparation of the remaining teeth. The tooth preparation was done by grinding up to 2 mm of enamel, for all the axial walls and incisal and occlusal planes. Preparation procedure was followed with two impression procedures with elastomers in standard trays for obtaining two experimental models.

For the experimental models with the conventional removable partial dentures (cRPDs), teeth were prepared to receive metal ceramic crowns and splinted in full arch reconstruction. The parallel guiding planes on proximal and lingual tooth surfaces on the crowned abutment retainers were established. The experimental model with the attachment retained removable partial dentures (aRPDs) included units with full arch metal-ceramic crowns with ball attachments (Bredent, Germany) positioned on distal surfaces of the abutment retainers. When the fixed restorations were finished, they were fitted to the models, verified and impressions were taken for the definite RPDs casts. The experimental models were restored with following prosthetic restorations used for strain distribution evaluation: conventional RPDs with Roach clasp as a type of extra-coronal retainer that originates from the denture framework going over the bucal periodontium and reaches the tooth undercut area from a gingival direction (T-bar design) and full coverage metal-ceramic crowns on the remaining teeth and lingual rest positioned on distally milled retainers; complex RPDs with Bredent attachments (ball) positioned in the distal surfaces of the milled retainers with consideration that all the remaining teeth were splinted, as previously in cRPD models.

One peculiarity of the design of the RPDs employed in the experiment implied cutting of the buccal wings as parts of the denture-saddles in order to visualize strain during the simulated occlusal loading. The experimental models were then sprayed to enable the DIC method to perform surface-strain analysis. The distances between sprayed points were changed under vertical loading. This phenomenon was registered by cameras.

The experimental models were placed in the standard tensile testing machine (Tinius Olsen, Germany). The applied occlusal force was 300 N, in accordance with literature data about maximal willing force in humans and consideration that the mastication force intensity decreased by reducing of teeth number [19]. The loading measurement was performed using the horizontal extension of the gnathodynamometer (Siemens, Germany). Occlusal (vertical) load was eccentric and it was directed to the cusps of artificial (acrylic) lower molars of experimental models. The reason for performing only two teeth loading was strictly experimental and was one of the inclusion criteria of this study. The acrylic teeth were loaded to visualize strain below the partial dentures. The study included only the posterior mandible viewed from lateral aspect excluding the anterior mandible. The mandible was supported by two metallic plates within a tensile testing machine.

Strain measurement was conducted using the Digital Image Correlation Method and the software Aramis (manufacturer GOM-Optical Measuring Techniques, Braunschweig, Germany) where stereophotogrammetric principles were used for analyzing models mobility. Generally, the system is based on two digital cameras (50 mm lenses with the 25 mm distance ring, (Schneider Kreuznach, Bad Kreuznach, Germany), trigger box, PC and the Aramis (software version 6.2.0., Braunschweig, Germany) and immediately after the calibration process, the photographing procedure was performed in accordance with the basic principles of the stereophotogrammetric measurements

[15, 16]. The Aramis software used in this experiment, detected three-dimensional (3D) changes on the surface of loaded objects and measured strain automatically [12, 13].

This was an experimental compressive static loading. Of the total number ($n=6$) of experimental models, 4 representative figures (virtual models) were selected following software-data processing and used to present behavior of models under load of 300 N.

An interpretation of the results was done using two statistical analyses for 6 models (three in each group): a) Two-way ANOVA was used in order to examine the differences in effectiveness of the type of model, specific segments of interest (AS and PS) and their mutual interaction on the strain values in models. The strains in models with different kind of prostheses and strains within the specific segments of interest were compared using two-way ANOVA. Significance level (α) was set to 0.05. ($P < 0.05$). All comparisons and calculations were made in package “stats” (Software R, Vienna, Austria); b) The post hoc t-test with Bonferroni correction. This test can compare only two values of strain at the time, and results for segments of interest and prostheses were obtained.

RESULTS

Certain differences were found between experimental models restored with two different types of RPDs under vertically loading conditions. Overall strain in cRPD experimental models (Figures 1, 2) was slightly higher than strain generated in aRPD experimental models (Figures 3, 4). An average

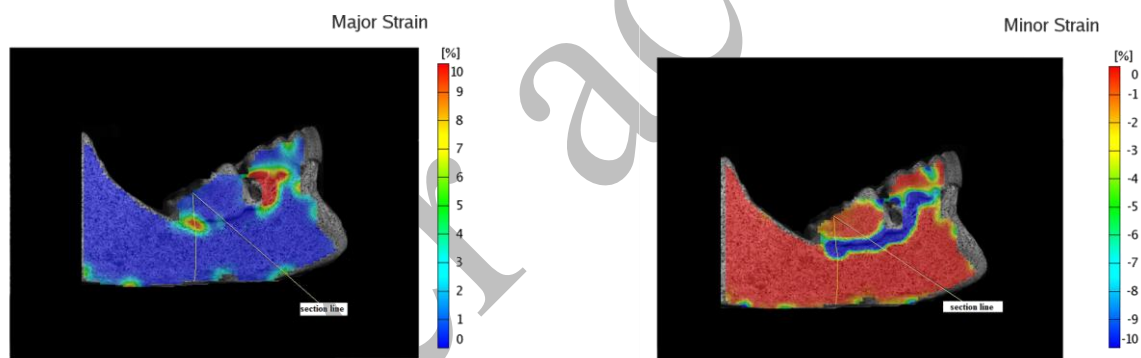


Figure 1. Major strain field of cRPD model showed high tensile strain up to 10% (red/yellow color) around clasp and in the retromolar area, proved by the scale next to figure.

Figure 2. Minor strain field of cRPD model showed high compressive strain with max value up to 10% assigned by green and blue colors and positive values on the scale.

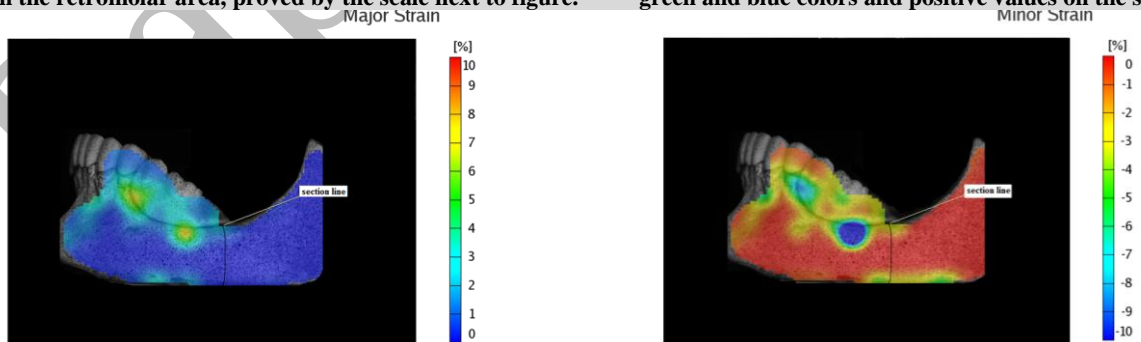


Figure 3. Major strain field of aRPD model indicated max values of tensile strain in the marginal bone below ball attachment; an equally portion of strain was found below free-end-saddle in the region of retromolar area.

Figure 4. Minor strain field of aRPD model indicated high compressive strain corresponds to negative values on the scale assigned by yellow, green and blue colors; beside the retromolar area strained due to offensive load was located just above this region, strain was detected in the marginal and apical bone below ball attachment.

displacement value for cRPD models was 0.54 mm and for aRPD models was 0.42 mm during loading of 300 N after software data processing. Tensile strain shows different strain propagation (Figures 1, 3) compared to compressive strain, as seen in figures 2 and 4. The highest tensile strain obtained loading the cRPD models was noticed just below the point of incidence in the retromolar area, and in the dried periodontium of the abutment teeth (7–10%), which is displayed showing colours determined by scales next to figures. Unlike tensile strain, the compressive strain was highly visualized along the entire zone of bone-denture contact within the upper part of the residual alveolar ridge, especially when loaded cRPD mandible models (9–10%).

The vertical-section line, as seen in figures 1–4, was set in software under the loading acting on acrylic lower molars. The section line changed its length before and after the experiment was performed. Obtained figures were efficient in visualizing strain field under vertical loading. Strain values were computed by the software based on the experimental measurement. Major and minor strain values (%) were presented on the scale.

The cRPD experimental models showed higher strain values during loading (Figures. 1, 2). Major strain values in the line section of the mandibles were ranged from 0 to 10%. Major strain values for the entire section length were presented in figure 5. The average major strain surrounding the upper part of mandibles was less than 1%. The highest strain values were noticed just below the cRPDs and in the retromolar area with the average major strain value between 6 and 7%. The buccal marginal periodontium of the distal abutments strained about 3–4%. The retentive clasps and occlusal rests strained, too (7%). The highest minor strain values (compressive strain) were especially detected in the “bone-denture” contact regions (9–10%).

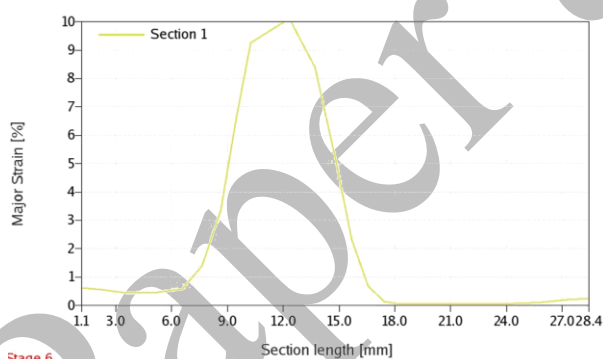


Figure 5. Diagram of cRPD section line shows the highest strain value in its middle segment corresponds to upper part of the residual ridges and marginal periodontium.

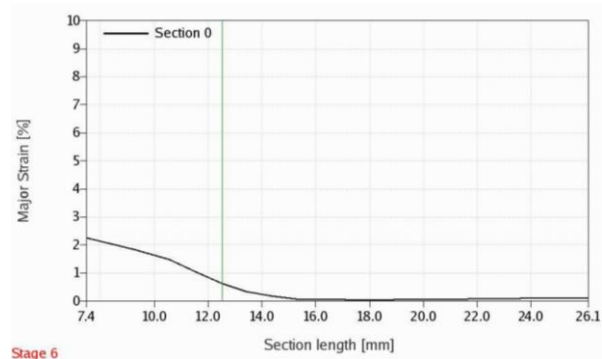


Figure 6. Diagram of aRPD section line describes slightly decreased values of strain along the section length unlike in cRPD models which may be of high relevance for inducing the uniform strain distribution.

For the aRPD experimental models, major and minor strain was computed under the same conditions presented in the previous cases (Figures 3, 4). Strain values in the line section were from 0 to 2.3%. The aRPDs line-sections indicated continuity of its flow, which was quite opposite in the case of cRPDs line-sections. Major strain values for the entire section length were shown in figure 6. The average strain on the area surrounding the upper part of mandibles was less than 1%. The highest

strain values are noticed just below the RPD, with the average value of strain between 6 and 7%. The buccal marginal periodontium of the distal abutments strained 6-7%. Strain of the attachments was 2%. Minor strain showed similar direction of the strain propagation as major strain, as seen in Figures 3 and 4.

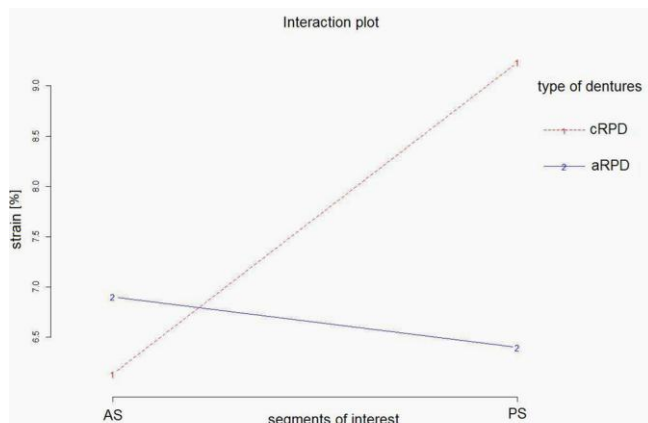


Figure 7. Interaction plot regarding the values of average strain for the cRPD and aRPD-models and segments of interest.

Relationship between types of the experimental models, segments of interest and strain values was displayed in the interaction plot (Figure 7). It was noticed that cRPD-models exhibited highest strain in posterior segments of interest with the peak over 9%, while the peak strain for aRPDs-models was obtained in AS (6.8%). A minimum strain in cRPD-models was measured for AS (to 6%). PS showed lower strain when consider aRPDs-models.

Significant differences in strain-values between material groups $F=15.5$; $p=0.00431$ were detected (Table 1). Furthermore, a statistically significant difference existed between region of interest with $F(2.18)=24.23$, with $p=0.00112$. Finally, there was interaction between the type of the sample

Table 1. Two-way Anova for prostheses type and segments of interest.

	df	Sum of Squares	Mean Square	F value	Pr(>F)
Prosthesis types	1	3.203	3.203	15.5	0.00431
Segments of interest	1	5.07	5.07	24.23	0.00112
Prosthesis types: Region	1	9.72	9.72	47.03	0.00013
Residuals	8	1.653	0.207		

and region of interest in the effect on strain values, with $F(4.18) = 47.03$; $p=0.00013$.

Comparison between two segments of interest

showed statistically significant difference in the experimental models restored with cRPDs ($p<0.01$) and statistical insignificance for the experimental models restored with aRPDs ($p>0.05$). Furthermore, both types of prostheses showed statistical significance when considered AS ($p<0.05$) and PS ($p<0.01$).

DISCUSSION

The study showed performances of the digital image correlation method (DIC) as a current technique employed to determine, visualize and measure strain on mandible surfaces during vertical loading of RPDs placed in situ. Full field, non-contact strain measuring was conducted using the Aramis software which produced photos of real-time strains for every measurement stage from the pattern surface. Using two digital cameras this optical system provided a synchronized stereo view of the specimen and sufficient data on the results showing the complete strain field during the tests. Several advantages of the DIC technique over other digital methods were established in the past:

resistance on the displacement of the observed model during measurement process and full field of strain measurement [10, 11, 12], low sensibility to ambient vibrations, ability to register rigid body motion and to measure 3D displacements in a high dynamic range (microns to millimeters) of measuring capacity [13] and high reproducibility of the DIC measuring [14]. In dental biomechanics DIC is often utilized for in vitro setups [11, 12, 13]. Whether it concerns about the biomechanical behavior of the human jaw under static or dynamic load [11–16], biomechanical testing of biomaterials [17] or photogrammetric measurements of initial tooth displacement under tensile force [15, 18] DIC has been confirmed as method especially suitable for 3D-strain measurements of dental materials and structures with complex geometry [9, 16] due to ability to catch non-linear surface strain in [13, 14].

The study was conducted as a static, non-impact, “in vitro” loading of the experimental models with different designs of dentures positioned “in situ”. Two types of replacements were compared and pinpointed the better one with respect to biomechanics. Knowing of the biomechanical behaviour of hard tissues (bone and teeth) and their interaction with replacements is important for the investigation of biomaterials and designs of replacements so, this type of research can improve prognosis and treatment planning in partially edentulous subjects. The researchers used cadaveric mandibles without soft tissue coverage thus may depend on the donor-related variability of the examined bone features. The absence of the elevator muscles and soft tissue as supported structures, and thus fixation of mandibles opposite to the real (physiological) conditions was another exclusion criteria addressed to disadvantages of this study [20]. Nevertheless, this study investigated the upper part of the mandibles adjacent to prostheses therefore, considering the biomechanical viewpoint the results are competent for arguing about the biomechanical behaviour of usually indicated RPDs. The study describes preparing all remaining teeth and restoring them with splinted porcelain fused to metal restorations. This was expensive, technically difficult and required radical amounts of tooth structure removal. Nevertheless, we were guided by the fact that a high percent of the partially edentulous subjects indicate signs and symptoms of periodontal disease and tooth wear of the tooth structure, thus, restored of such teeth was considered as an imperative. Additionally, treatment of the remaining teeth was done to achieve similar loading conditions of the supporting dental structure, for both types of RPD-restored experimental models, as much as possible. Following this criterion, experimental models restored with aRPDs included ball over slide attachment. Although, both types of attachments whether ball or slide are indicated for rehabilitation of the Kennedy Class 1 partial edentulism dimensions of the clinical crowns and length of the residual ridges/free-end saddles were the critical factors to opt for the ball attachments as more preferable.

In this experiment, results acquired from the Aramis system were sorted into two groups of experimental models and two groups of interest locations (segments). Dentures, as the part of the experimental models and locations of interest within the tested models presented two factors which caused different values of strains of the loaded models. Their mutual effect on experimental models

was presented in the interaction plot where the connection between experimental results was visualized.

Strains for different types of experimental models and different segments of interest were compared using two-way ANOVA. Two-way ANOVA was employed to determine whether there were statistically significant differences between the tested experimental groups. Prosthesis type and location of interest represented factors of influence. The strain was considered as the dependent variable. Both factors such as prosthesis type and location of interest showed significant influence. Significant differences in the strain values existed between two groups of prostheses for both segments of interest ($p < 0.05$, $p < 0.01$; Table 2), and also in two different locations of measured surface but only for cRPDs models ($p < 0.001$; Table 3). Although ANOVA revealed statistically significant

Table 2. Comparison between prostheses types for different segments of interests; Post Hoc.

Segments	cRPD	aRPD	<i>p</i> value	Bonferroni
AS	6.13 (0.21)	6.9 (0.4)	$p < .05$	0.042
PS	9.23 (0.7)	6.4 (0.36)	$p < .01$	0.0034

Table 3. Comparison between segments of interest for different prostheses types; Post Hoc.

Prostheses	AS	PS	<i>p</i> -value	Bonferroni
cRPD	6.13 (0.21)	9.23 (0.7)	$p < .01$	0.0018
aRPD	6.9 (0.4)	6.4 (0.36)	$p > .05$	0.18

differences between the type of the strained models, location of interest and interaction in these two factors, this analysis could not point out between which groups of models and locations of interest these differences actually existed. Thus, additional post hoc t test was introduced to reveal statistical significance between observed variables and to find out where these differences actually occurred. In order to provide a more valid comparison and to reduce type I error, the conservative Bonferroni correction was applied. Therefore, all three null hypotheses were rejected, and alternative ones were adopted, which state that strain was dependent from the prostheses used and from the locations within the region of interest. Also, there was an interaction between prostheses and segments of interest in their effect on the strain values.

Although strain varied significantly between locations of interest, dentures' effect was also noticed. Namely, models with cRPDs showed highest strains for posterior locations of interest (PS) while loaded models restored with aRPDs induced highest strain in the anterior locations of interest (AS). The cRPD-models displayed lowest strain in AS. Furthermore, cRPD-models showed statistically significant difference between strain in AS and PS, while aRPD-models didn't. Although anterior segments below aRPDs strained almost 1% higher than below cRPDs, posterior segments strained with higher statistical significance when considered different types of prostheses.

The study investigated an impact of two types of bilaterally-distally-extended removable partial dentures on mandibles with shortened dental arches. Shortening of the buccal wings of the RPD saddles in the experimental models was done to obtain a wider field for optical observation of the upper part of the mandibles. Region of interest included upper part of mandible bone, the buccal cortical laminae below the abutments and retromolar area. Two different kinds of strain were presented in this study: the maximum value of minimum principal strain expressed as minor strain-

compressive strain, and the maximum value of maximum principal strain, expressed as major strain-tensile strain. For a complete understanding of the biomechanical behavior of RPD-mandible models it was necessary to take into account all major and minor strain values and not only strain within section line.

Generally, compressive strain was generated by the compressive force (load) impact. This load affected the denture-saddle movement which induced strain at first in the bone-denture contact area (compressive strain) and then through the entire residual alveolar ridge depending on the force intensity. Consequently resulted tensile strain was the factor of resistance the mandibles, the way in which mandibles withstood the compressive force. The type of replacements and connection with the distal abutments may also influence on the major and minor strain values. Practically, the study investigated two different modalities of RPDs through the comparing the tensile and compressive strain between them.

When an RPD was considered to replace missing posterior teeth in the distal free-end edentulous ridges, careful planning of design was very important. Namely, in this situation we had to restore biologically two different tissues in order to achieve uniform distribution of the occlusal forces on the periodontal tissue of the remaining teeth and in the mucoperiosteum on the edentulous alveolar ridges. Most of the cases with bilateral shortened dental arch require specific management of the remaining teeth. The fixed restorations-full crowns have been used for this purpose, usually. In this research the restorations of choice were full arch metal ceramic crowns. The milled guiding planes on the lingual and proximal surfaces of these restorations improved the retention and stability of dentures [4]. While the cast circumferential clasp causes some kind of elastic type of connection between abutment and RPD, when precision attachments were selected to retain an RPD, a removable prosthesis was “rigidly” connected to the abutment teeth.

The cRPD-experimental models were fabricated to minimize the torque applied to the abutments by splinting all remaining teeth into one-single unit composed of the full cast restoration prepared to receive clasp-retained RPDs. The RPDs made in this way provided displacement of the free-end saddles toward the edentulous ridge during vertical loading conditions. The displacement caused load transfer toward the mandibular edentulous ridge which resulted in the appearance of a large amount of strain beneath the denture saddle, as seen in Figures 1 and 2. When the functional occlusal load is induced on this kind of distal-extension RPD, a rotary movement usually occurs around the fulcrum of the terminal abutments [5, 8]. This phenomenon not only decreases the denture function and causes the patient’s discomfort, but also traumatizes the supporting tissues of dentures. A good design for a distal-extension RPD should prevent rotary movement in order to protect the supporting tissues.

Opposite to cRPD-models, the aRPD-models had all remaining teeth splinted in the full-arch metal ceramics retained with attachments to RPDs. The RPDs retained in such a way to fulfil current demand in rehabilitation of the oral function and protection remaining teeth and residual ridges. These

“rigid design dentures” with rigid precision ball attachments develop lower movement to those with resilient attachments [2]. As we know, the rigid-precision attachments have different mechanisms, nevertheless the variation in the transfer of functional loads between conventional RPDs and complex RPDs has not been clarified yet.

The models were subjected to the vertical forces. It means that under compressive load might influence only vertical displacements of denture base. Clinically, occlusal rests or attachments must resist the multidirectional loads. Hence, an impact of the mentioned factors should be considered in future investigations before any conclusion.

The cRPD-models showed a higher score of the overall strain than aRPD-models including especially the compressive (minor) strain. It means that the whole denture saddles compressed residual alveolar ridges because of the elastic properties of the cast clasps. This could be explained through the fact of different kind of connection within two types of prostheses. In the case of aRPD-models higher tensile (major) strain was found in the bone adjacent to the distal abutments especially when considered the marginal bone than in cRPD-models, as a consequence of the rigid connection. Nevertheless, residual alveolar ridges of cRPD-models showed higher tensile strain than of aRPD-models. Generally, the major strain (tensile strain) in the bone adjacent to the distal abutments showed lower values of intensity compared to strain of the alveolar ridges. This can be explained by the fact that splinted metal-ceramic crowns distributed lesser strain to the supporting structures: adjacent bone and abutments [13]. This was supported by the idea that rigidly connecting of the adjacent teeth, leads to more evenly distribute to both or each single abutment including retainers [21]. The effect of splinting the adjacent teeth was limited locally, considering the direction of strain was found in the upper part of all models.

Our findings confirm previous regarding association between the rigidity of connection to the abutment and denture mobility [3]. Clasp retained RPDs were supposed to be more elastic than attachment RPDs and therefore higher mobility of cRPDs were observed. Thus, higher rate of strain can be expected beneath cRPDs. In contrast the flexibility of attachment was lower and needed less amount of bone tissue support under the denture base.

The attachment RPDs may not be suitable therapy solutions in the case of periodontally weakened abutment teeth due to instability and therapeutic failure. These situations request splinting of periodontally compromised teeth into single unit followed by adequately designed and adjusted RPDs with consideration of the denture extension and the level of periodontal damage [12, 21].

CONCLUSION

Visualizing the biomechanical behaviour of RPDs placed in situ on supporting dental tissues can improve the design of RPDs and preserve abutment teeth and bone. This will avoid possible failures in current dental practice. Within limitations and based on the results of this study, it can be said that higher strain was observed below the clasp RPDs, particularly if considered movement of the

distal portion of the free-end saddles caused by the teeth and dentures vertical displacement. The findings proved that attachment RPDs generated less strain in the residual alveolar ridges, thus regarding the biomechanical viewpoint, can be considered as the better choice for rehabilitation of the Kennedy Class 1 partial edentulism compared to clasp removable partial dentures. However, high strain was found in the bone adjacent to distal abutments. In accordance with the tasks provided by null hypothesis final conclusions were derived: 1) Mean strain was significantly different for all models considering its distribution and values. This fact could be the reason of differences that exist between two types of RPDs with different type of connections with the adjacent teeth; 2) Mean strain values showed significant differences between anterior and posterior mandibular segments of cRPD models. However, mean strain in AS and PS was similar in aRPD models probably due to aRPDs generated uniform strain distribution in mandibles compared to cRPDs. 3) Findings provide a noticeable difference in effect induced by interaction between prostheses and segments of interest due to increment movements of two types of RPDs towards the residual ridges.

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