DOI: https://doi.org/10.2298/SARH170725181T
UDC: 616.314-085

ORIGINAL ARTICLE / ОРИГИНАЛНИ РАД

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

Ivan Tanasić[1], Ljiljana Tihaček-Šojić[2], Aleksandra Milić-Lemić[2]

[1]Obrenovac Medical Health Center, Belgrade, Serbia;
[2]University of Belgrade, School of Dental Medicine, Department of Prosthodontics, Belgrade, Serbia

SUMMARY

Introduction/Objective Current biomechanical analyses can provide full view of the 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 removable partial dentures, commonly indicated in the conventional rehabilitation of partially edentulous patients.

Methods This *in vitro* study included two groups of experimental models composed of the mandibles (Kenedy 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 called the retromolar area. Strain values in the experimental models with clasp removable partial dentures ranged 0–10%. Strain values in the experimental models with attachment – removable partial dentures ranged 0–2.3%.

Conclusion The findings showed that the attachment retaining 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

INTRODUCTION

The success or failure of the prosthetic treatment of patients rehabilitated with a removable partial denture (RPD) depends on the oral health state, the preparation designs on the available tooth structure, and the long-term prognosis of the 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 RPDs [2, 3, 4]. Important factors like careful planning, designing, and preparation of remaining teeth are essential, since adequately prepared rest seats and precisely fitting rests will provide mutual assistance between teeth and the 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 the longevity of the remaining teeth, bone, and prosthesis made to replace the missing oral structures. Therefore, a sophisticated RPD design manufactured in correlation with properly prepared abutments fulfils the functional, prophylactic, and aesthetic demands placed upon it.

Although significant explanations of biomechanical behavior of RPDs were proposed in the last few decades, our understanding of the ideal design is still lacking [2–6]. Some numerical and photoelastic models and *in vivo* analyses estimated and showed the RPD displacement under occlusal loading [3, 5–8]. Practical methods for biomechanical investigation of biomaterials and the jawbone are based on either contact or non-contact mechanisms for strain/displacement measurements [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 RPDs most commonly used in the conventional rehabilitation of partially edentulous patients. The study employed the digital image correlation (DIC) 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 a surface that surrounded RPDs and distal retainers/abutments. In order to facilitate the interpretation of the results, we divided the region of interest into two locations

Received • Примљено:
July 25, 2017
Ревизија • Revised:
September 25, 2017
Accepted • Прихваћено:
September 27, 2017
Online first: October 3, 2017

Correspondence to:
Ivan TANASIĆ
Obrenovac Medical Health Center
11000 Belgrade, Serbia
doktorivan@hotmail.com
prosthodontics.clinic@gmail.com

(segments): the anterior segment (AS), corresponding the supporting bone tissue-adjacent abutment, and the posterior segment (PS), corresponds to the retromolar area.

Three sets of null hypotheses 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

Six dried, partially edentulous mandibles (two groups of three models) with bilaterally shortened dental arches (Kennedy Class 1) with first premolars remaining (8 ≤ n ≤ 10; n = number of the remaining teeth) were used in the experiment: three mandibles were restored with conventional clasp-retained removable partial dentures (cRPDs) and another three mandibles were restored with attachment-retained removable partial dentures (aRPDs). The mandibles were borrowed from the Laboratory for Anthropology of the Institute of Anatomy, Faculty of Medicine in Belgrade, Serbia. The donors were men, in their late sixties. The mandibles were checked to exclude any damage. The chosen mandibles were immersed in the 0.9% NaCl for eight hours to reach the volume and elasticity considered in *in vitro* experiments [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 the 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. The preparation procedure was followed by two impression procedures with elastomers in standard trays for obtaining two experimental models.

For the experimental models with cRPDs, the 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 medical GmbH & Co.KG, Senden, 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 RPD casts. The experimental models were restored with the following prosthetic restorations used for strain distribution evaluation: conventional RPDs with Roach clasp as the type of extra-coronal retainer that originates from the denture framework going over the buccal 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 TMC, Horsham, PA, USA). 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 the number of teeth [19]. The loading measurement was performed using the horizontal extension of the gnathodynamometer (Siemens, Munich, Germany). Occlusal (vertical) load was eccentric and it was directed at the cusps of artificial (acrylic) lower molars of the experimental models. The reason for performing only two-teeth loading was strictly experimental and was one of the inclusion criteria of the study. The acrylic teeth were loaded to visualize the 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 DIC method and the Aramis software (GOM-Optical Measuring Techniques, Braunschweig, Germany), in which stereophotogrammetric principles were used for analyzing model mobility. Generally, the system is based on two digital cameras (50 mm lenses with a 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 the strain automatically [12, 13].

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

Interpretation of the results was done using the following two statistical analyses for the six models (three in each group):

- 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 the 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).

- 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. The overall strain in the cRPD experimental models (Figures 1 and 2) was slightly higher than the strain generated in the aRPD experimental models (Figures 3 and 4). The average displacement value for the cRPD models was 0.54 mm, and 0.42 mm for the aRPD models during the loading of 300 N after software data processing. Tensile strain showed different strain propagation (Figures 1 and 3) compared to compressive strain, as seen in Figures 2 and 4. The highest tensile strain for the loading of 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 colors 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 cRPD mandible models were loaded (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 the 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 and 2). Major strain values in the line section of the mandibles ranged 0–10%. Major strain values for the entire section length are 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 as well (7%). The highest minor strain values (compressive strain) were especially detected in the “bone–denture” contact regions (9–10%).

For the aRPD experimental models, major and minor strain was computed under the same conditions presented in the previous cases (Figures 3 and 4). Strain values in the line section were 0–2.3%. The aRPD line-sections indicated continuity of its flow, which was quite opposite in the case of cRPD line-sections. Major strain values for the entire section length are shown in Figure 6. The average strain on the area surrounding the upper part of the 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 the major strain, as seen in Figures 3 and 4.

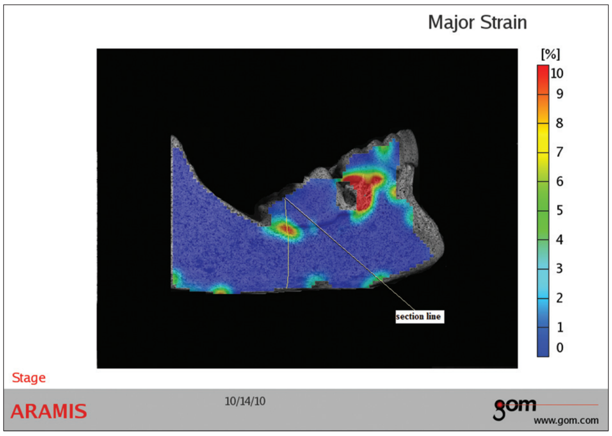

Figure 1. Major strain field of the clasp-retained removable partial dentures model showed high tensile strain up to 10% (red/yellow) around the clasp and in the retromolar area

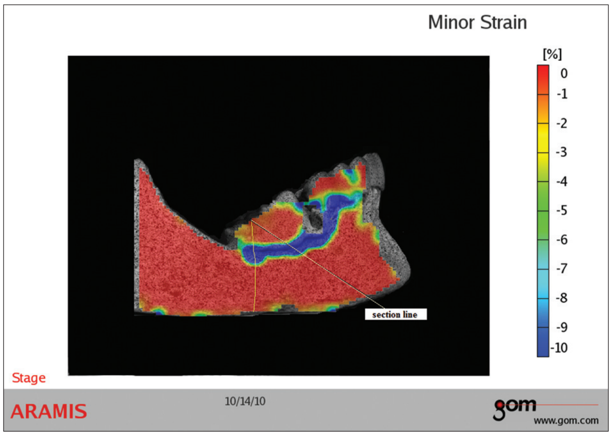

Figure 2. Minor strain field of the clasp-retained removable partial dentures model showed high compressive strain with maximum reaching 10%, assigned to green and blue colors and negative values on the scale

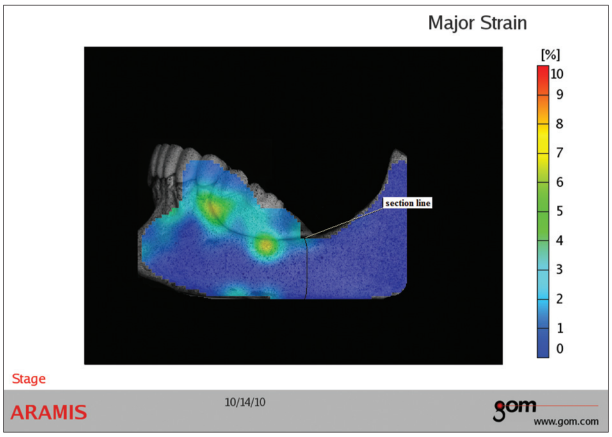

Figure 3. Major strain field of the attachment-retained removable partial dentures model indicated maximum values of tensile strain in the marginal bone below the ball attachment; equal strain was found below the free-end saddle in the retromolar area

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

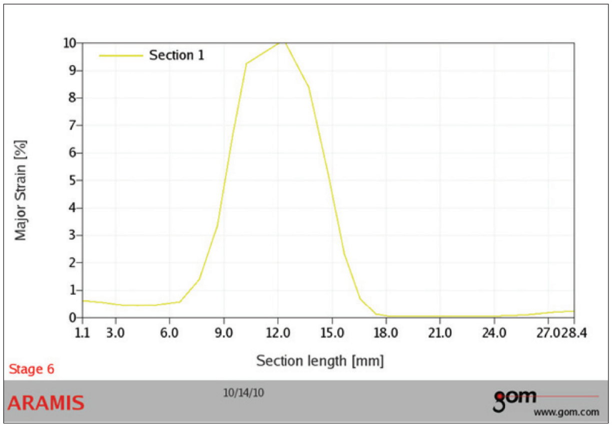

Figure 5. Clasp-retained removable partial dentures section line shows that the highest strain value in its middle segment corresponds to the upper part of the residual ridges and marginal periodontium

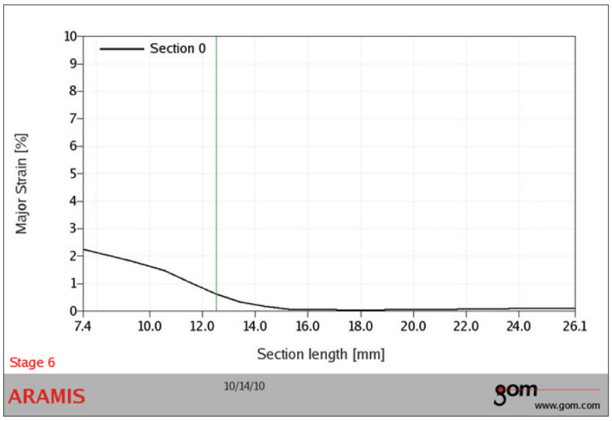

Figure 6. Attachment-retained removable partial dentures section line depicts slightly decreased values of strain along the section length unlike in the clasp-retained removable partial dentures models, which may be of high relevance for inducing uniform strain distribution

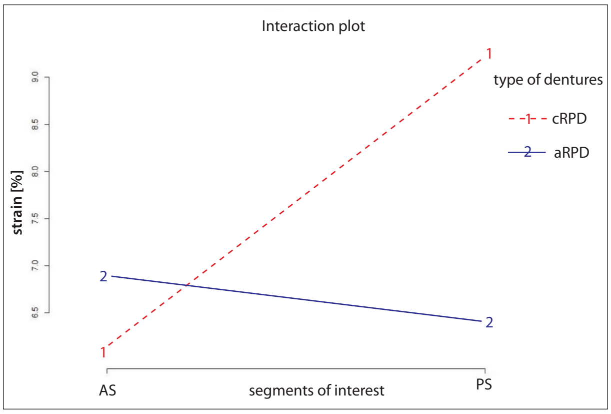

Figure 7. Attachment-retained removable partial dentures section line depicts slightly decreased values of strain along the section length unlike in the clasp-retained removable partial dentures models, which may be of high relevance for inducing uniform strain distribution

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

Parameter	df	Sum of squares	Mean square	F	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		

*Probabilities for the segments of interest represent significant difference ($p < 0.001$)

The relationship between types of the experimental models, segments of interest, and strain values is displayed in the interaction plot (Figure 7). It was noticed that cRPD models exhibited the highest strain in posterior segments of interest with the peak over 9%, while the peak strain for aRPD models was obtained in AS (6.8%). The minimum strain in cRPD models was measured for AS (up to 6%). PS showed lower strain when considering aRPD 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 an interaction between the type of the sample and the region of interest in the effect on strain values, with $F (4.18) = 47.03$; $p = 0.00013$.

A comparison between the two segments of interest showed a 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 for AS ($p < 0.05$) and PS ($p < 0.01$).

DISCUSSION

The study showed performances of the DIC method as a current technique employed to determine, visualize and measure the strain on mandible surfaces during the 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 the measurement process and full field of strain measurement, 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, and high reproducibility of the DIC measuring [10–14]. In dental biomechanics, DIC is often utilized for *in vitro* setups [11, 12, 13]. Whether it concerns the biomechanical behavior of the human jaw under static or dynamic load, biomechanical testing of biomaterials, or photogrammetric measurements of initial tooth displacement under tensile force, the DIC has been confirmed as a method especially suitable for 3D-strain measurements of dental materials and structures with complex geometry due to the ability to catch non-linear surface strain in the tested specimens [9, 11–18].

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 the better one was determined 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. This fact distinguishes the donor-related variability of the examined bone features as the key factor when performing the DIC experimental analysis. The absence of the elevator muscles and soft tissue as supportive structures, and thus the fixation of mandibles in contrast to the real (physiological) conditions, was another exclusion criteria addressed to the disadvantages of this study [20]. Nevertheless, this study investigated the upper part of the mandibles adjacent to prostheses; therefore, from the biomechanical standpoint, the results are adequate 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 high percentage of partially edentulous subjects indicates signs and symptoms of periodontal disease and tooth wear of the tooth structure; thus, restoration of such teeth was considered 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 rather than 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 a part of the experimental models and locations of interest within the tested models, presented two factors that 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.

Table 2. Comparison between prostheses types for different segments of interests (post hoc)

Segments	cRPD	aRPD	p-value	Bonferroni
AS	6.13 (0.21)	6.9 (0.4)	< 0.05	0.042
PS	9.23 (0.7)	6.4 (0.36)	< 0.01	0.0034

AS – anterior segment; PS – posterior segment; cRPD – clasp-retained removable partial dentures; aRPD – attachment-retained removable partial dentures

Table 3. Comparison between segments of interest for different prostheses types (post hoc)

Prostheses	AS	PS	p-value	Bonferroni
cRPD	6.13 (0.21)	9.23 (0.7)	< 0.01	0.0018
aRPD	6.9 (0.4)	6.4 (0.36)	> 0.05	0.18

AS – anterior segment; PS – posterior segment; cRPD – clasp-retained removable partial dentures; aRPD – attachment-retained removable partial dentures

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 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), as well as in two different locations of measured surface, but only for cRPD models ($p < 0.001$; Table 3). Although ANOVA revealed statistically significant differences between the type of the strained models, location of interest, and interaction of these two factors, this analysis could not determine 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. In addition, 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 the highest strain in the anterior locations of interest (AS). The cRPD models displayed the lowest strain in the AS. Furthermore, cRPD models showed a statistically significant difference between strains in the AS and the PS, while aRPD models did not. Although anterior segments below aRPDs strained almost 1% higher than below cRPDs, PSs strained with higher statistical significance in regard to different types of prostheses.

The study investigated the 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 the 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 the section line.

Generally, compressive strain was generated by the compressive force (load) impact. This load affected the denture–saddle movement, which initially induced strain 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 increased the mandible resistance, thus contributing to mandibles withstanding the compressive force load. The type of replacements and connection with the distal abutments may also influence the major and minor strain values. Practically, the study investigated two different modalities of RPDs through 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. Fixed restorations – full crowns – have been usually used for this purpose. 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 connection between the abutment and the 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, 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.

In contrast to the cRPD models, the aRPD models had all the remaining teeth splinted in the full-arch metal-ceramics retained with attachments to RPDs. The RPDs retained in such a way fulfil a current demand for rehabilitation of the oral function and for protection of remaining teeth and residual ridges. These "rigid design dentures" with rigid precision ball attachments are considered to be less mobile/movable compared to dentures with resilient attachments [2]. As we know, 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. Vertical displacement of the denture base presented in this study was a consequence of the compressive vertical load. Clinically, occlusal rests or attachments must resist multidirectional loads. Hence, the influence of the mentioned factors should be considered in future investigations before any conclusion is made.

The cRPD models showed a higher score of the overall strain than aRPD models, including especially the compressive (minor) strain. This means that the whole denture saddles compressed residual alveolar ridges because of the elastic properties of the cast clasps. This could be explained by different kinds of connections 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 concerning 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 those in the 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, i.e. adjacent bone and abutments [13]. The idea of rigidly connected adjacent teeth was supported by a previous investigation, which confirmed the equitable distribution of strain to each single abutment and retainer in the block construction [21]. The effect of splinting adjacent teeth was limited locally, considering that the direction of strain was found in the upper part of all models.

Our findings confirm previous ones regarding the 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 was observed. Thus, higher rate of strain can be expected beneath cRPDs. In contrast, the flexibility of the attachment was lower and needed less amount of bone tissue support under the denture base.

Attachment RPDs may not be suitable therapy solutions in cases 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 we consider 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, and thus, from the biomechanical standpoint, can be considered a better choice for the rehabilitation of the Kennedy Class 1 partial edentulism compared to clasp RPDs. However, high strain was found in the bone adjacent to distal abutments. In accordance with the tasks provided by null hypothesis, the following conclusions were derived:

1. The mean strain was significantly different for all models, when its distribution and values are considered. This fact could be the reason for differences that exist between two types of RPDs with different types of connections with the adjacent teeth.
2. The mean strain values showed significant differences between mandibular AS and PS of cRPD models. However, the mean strain in AS and PS was similar in aRPD models probably due to the fact that aRPDs generated uniform strain distribution in mandibles compared to cRPDs.
3. The findings provide a noticeable difference in the effect induced by interactions between prostheses and segments of interest due to incremental movements of two types of RPDs toward the residual ridges.

ACKNOWLEDGMENT

The authors would like to thank the Faculty of Mechanical Engineering of the University of Belgrade, Serbia, and the Institute for Anthropology, Faculty of Medicine, University of Belgrade, Serbia.

REFERENCES

1. Wright EW. Prosthetic management of the periodontally compromised dentition. J Calif Dent Assoc. 1989; 17:56–60.
2. Saito M, Miura Y, Notani K, Kawasaki T. Stress distribution of abutments and base displacement with precision attachment- and telescopic crown-retained removable partial dentures. J Oral Rehabil. 2003; 30(5):482–7.
3. Igarashi Y, Ogata A, Kuroiwa A, Wang CH. Stress distribution and abutment tooth mobility of distal-extension removable partial dentures with different retainers: an in vivo study. J Oral Rehabil. 1999; 26(2):111–6.
4. Chaiyabutr Y, Brudvik JS. Removable partial denture design using milled abutment surfaces and minimal soft tissue coverage for periodontally compromised teeth: A clinical report. J Prosthet Dent. 2008; 99(4):263–6.
5. Jin X, Sato M, Nishiyama A, Ohyama T. Influence of loading position of mandibular Unilateral distal extension, Removable Partial Dentures on movements of abutments tooth and denture base. J Med Dent Sci. 2004; 51(3):155–63.
6. Kibi M, Ono T, Dong J, Mitta K, Gonda T, Maeda Y. Development of an RPD CAD system with finite element stress analysis. J Oral Rehabil. 2009; 36(6):442–50.
7. Eto M, Wakabayashi N, Ohyama T. Finite Element analysis of deflections in major connectors for maxillary RPDs. Int J Prosthodont. 2002; 15(5):433–8.
8. Aras K, Hasanreisog˘lu U, Shinogaya T. Masticatory performance, maximum occlusal force, and occlusal contact area in patients with bilaterally missing molars and distal extension removable partial dentures. Int J Prosthodont. 2009; 22(2):204–9.
9. Tanasić I, Tihaček-Šojić Lj, Milić-Lemić A. Optical metrology analysis of the lower jaw deformations. Vojnosanitet pregl. 2011; 68(4):336–40.
10. Akca K, Cehreli MC. A photoelastic and strain-gauge analysis of interface force transmission of internal-cone implants. Int J Periodont Res Dent. 2008; 28(4):391–9.
11. Tanasić I, Milic-Lemic A, Tihacek-Sojic Lj, Stancic I, Mitrovic N. Analysis of the compressive strain below the removable and fixed prosthesis in the posterior mandible using a digital image correlation method. Biomech Model Mechanobiol. 2012; 11(6):751–8.
12. Tihacek Sojic Lj, Milic Lemic A, Tanasic I, Mitrovic N, Milosevic M. Compressive strains and displacement in a partially dentate lower jaw rehabilitated with two different treatment modalities. Gerodontology. 2012; 29(2):e851–7.
13. Tiossi R, Lin L, Rodrigues RCS, Heo YC, Conrad HJ, de Mattos Mda G, et al. Digital image correlation analysis of the load transfer by implant-supported restorations. J Biomech. 2011; 44(6):1008–13.
14. Schmidt T, Tyson J, Galanulis K. Full-field dynamic displacement and strain measurement using advanced 3D image correlation photogrammetry: Part 1. Experimental Technic. 2003; 27:47–50.
15. Göllner M, Holst A, Berthold C, Schmitt J, Wichmann M, Holst S. Noncontact intraoral measurement of force-related tooth mobility. Clin Oral Investig. 2010; 14(5):551–7.
16. Sztefek P, Vanleene M, Olsson R, Collinson R, Pitsillides AA, Shefelbine S. Using digital image correlation to determine bone surface strains during loading and after adaptation of the mouse tibia. J Biomech. 2010; 43(4):599–605.
17. Tanasić I, Tihaček-Šojić Lj, Mitrović M, Milić-Lemić A, Vukadinović M, Marković A. An attempt to create a standardized (reference) model for experimental investigations on implant's sample. Measurement. 2015; 72:37–42.
18. DuChesne A, Unnewehr M, Schmidt PF, Sotonyi P, Brinkmann B, Piffko J, et al. Deformation characteristics of the human mandible in low impact experiments. Int J Leg Med. 2003; 117(5):257–62.
19. Muller F, Heath MR, Ott R. Maximum bite force after the replacement of complete dentures. Gerodontology. 2001; 18(1):58–62.
20. Vollmer D, Meyer U, Joos U, Vegh A, Piffko J. Experimental and finite element study of a human mandible. J Cranio-Maxillofac Surg. 2000; 28:91–6.
21. Yamashita J, Wang Q, Dechow PC. Biomechanical effects of fixed partial denture therapy on strain patterns of the mandible. J Prosthet Dent. 2006; 95(1):55–62.

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

Иван Танасић[1], Љиљана Тихачек-Шојић[2], Александра Милић-Лемић[2]

[1]Дом здравља Обреновац, Београд, Србија;
[2]Универзитет у Београду, Стоматолошки факултет, Катедра за стоматолошку протетику, Београд, Србија

САЖЕТАК

Увод/Циљ Савремене биомеханичке анализе омогућавају комплетну визуелизацију деформација од оптерећивања различитих зубних надокнада у протетској рехабилитацији. Циљ ове студије је био да анализа дистрибуције деформација унутар потпорних ткива испод два различита типа најчешће коришћених парцијалних скелетираних протеза.
Методе *In vitro* студија је обухватила две групе експерименталних модела доњих вилица (Кенеди 1 класа крезубости) и два типа парцијалних скелетираних протеза. Модели 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 скелетиране 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 скелетирана протеза; деформација кости