

Visualizing Strain Behavior in the Anterior Part of the Vertically Loaded Mandible Using Digital Image Correlation Method

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Abstract

The goal of this study was to analyse the surface strains in the anterior part of the mandible models by using the optical method. Dried mandibles with shortened dental arch (Kennedy class 1) were restored with two types of restorations: removable partial denture (RPD) and fixed partial denture-cantilever (FPD). After preparation, RPD and FPD mandible models were placed in the standard press system (tensile testing machine) where were tested. The Percentage size of the RPD line section strains was from 0 to 0.22 %. Percentage size of the FPD line section strains was from 0 to 0.5 %. Findings provide that RPD therapy induced less strain in the marginal bone of the anterior mandible. When it comes to FPD model, strains were uniformly concentrated in the alveolar bone around the abutment teeth.

Keywords: Mandible; Strain; Removable Partial Denture; Cantilevering; Digital Image Correlation Method

Introduction

Biomechanical behaviour of the posterior segments of mandible was previously assumed due to fact that mastication is predominantly supported by posterior teeth and that direction of masticatory forces is determined by direction of masticatory muscles. Reports have shown differences in strain distribution between cantilevered fixed restorations (FPDs) and removable partial dentures (RPDs) [1,2], due to cantilever FPDs induced less strain and displacement in the bone of residual ridge [1-3]. However, high strain affected the alveolar bone around the abutment teeth [2].

This study was based on the fact that the biomechanical interaction occurred between dried mandibles with bilaterally shortened dental arches (Kennedy class 1) and two viable options made for the case of bilaterally shortened dental arches: RPD (removable partial denture) and FPD (fixed partial denture), as previously mentioned [2]. Both conventional treatment options (RPD and FPD) can achieve relatively high rate of therapeutic success however the long-term biomechanical consequences on supporting tissues are still very questionable. As a typical negative side of FPD treatment, bone resorption can compromise the success of the FPD treatment. This can also be considered when treated with RPDs where two aspects of resorption have been defined: resorption of residual ridges and resorption of bone adjacent to the remaining teeth. While the distal extension base of RPDs generates movements in various directions under occlusal loading, the surrounding bone may resorb away from FPD abutments and thus bone support becomes compromised [4]. Additionally, tilting and intrusion-movements of anterior teeth during biting [5] if inappropriate can induce resorption of anterior teeth splinted as single unit. Initially, high stress/strain generated by excessive masticatory forces leads to consecutive resorption which can be, in accordance with mandibular anatomy and spongy-bone, very significant considering anterior mandible. One of the main tasks of clinicians regarding potential movements is to manage the proper design of RPDs including milled crowns or properly prepared rest seats to provide adequate

denture-placing and stability and to avoid overloading the supporting tissues and consequently overpower the physiological limits of the bone tissue with resultant resorption and subsequent failure of RPDs [6].

This study was conducted to visualize around below the anterior abutment teeth who were prepared to receive technically different types of dental restorations regarding connection: attachment retained RPD and cross-arch bilateral 11-unit cantilever-FPD. Despite disadvantages, cantilever-FPD are still restoration of choice for the case of partial edentulism, especially considering age and comfort [7]. Nevertheless, an impact that the abovementioned restorations have on supporting anterior abutment teeth is still unknown in current dental practice. Although cantilever FPD is a rigid single unit restoration with the attributes of the single-arm lever, it seems that similar features are presented in attachment retained RPDs considering periodontal status of distal abutments [8]. Several studies on occlusion and mastication have researched strain patterns in the periodontium including tooth, alveolar bone, periodontal ligament [9-12], and highlighted the role of the alveolar bone which detected to be subsequently strained. In this experimental work was assumed that when occlusal load is applied to tooth crowns a strain transmission to the surrounding bone will be established with spatial distribution throughout the object i.e. anterior mandible. It was preferred to choose the digital image correlation method (DIC) for strain analysis for the purpose of validation, since this method can provide a full view of strain fields in an entire region of interest [13].

The study aimed to visualize and determine strain in anterior part of mandibles restored with two viable treatment options: attachment retained RPD and bilaterally extended FPD (cantilever-FPD). Additionally, to compare strain in the RPD and FPD models. The study considered only the vestibular part of the anterior mandible due to strain on vestibular surface was higher than on lingual surface [14].

Methods

Two dried mandible (male, late fifties) were inspected and evaluated in accordance with previous inclusion and exclusion criteria (Kennedy class 1 mandibular arches, an absence of metabolic bone-disease etc.) [1,2,11].

After preparation of mandibles in the physiological (saline) solution (0,9% NaCl) for 24 hour to reach some volume and elasticity [1] and drying at the temperature of 27°C, preparation of the remaining teeth for receiving porcelain fuse to metal (PFM) restorations was performed [2]. Following preparation of the abutment teeth based on the main biomechanical requirements for teeth-preparation [15] and standard impression procedures of the supporting tissues, two types of restorations were fabricated: complex removable partial denture (RPD) in combination with full coverage cast porcelain fused to metal (PFM) crowns on remaining teeth with Bredent ball attachments used to connect PFM crowns and RPD into functional union; cantilevered-FPD with eleven unit PFM fabricated on the prepared mandible teeth. In that way, two experimental models (RPD and FPD) with dentures positioned in situ were prepared to be utilized for DIC investigation, as described in previous report [11]. Both models were placed in the standard tensile testing machine-press system and subjected to loads of 0 to 300 N (with the interval of 100 N) applied on occlusal surfaces of posterior teeth (beyond canines). The load was directed simultaneously towards the left and right sides of the mandibles. It was considered that the maximal willing force in humans decreases with the teeth loos and depends of muscular strength and region of interest, whether anterior or posterior [16]. Measurements of strain were conducted using the Digital Image Correlation Method (GOM-Optical Measuring Techniques, Braunschweig, Germany). A composition of the system includes two digital cameras and software Aramis (GOM-Optical Measuring Techniques, Braunschweig, Germany, version 6.2.0.). Mobile cameras photographed distance between reference points before load was applied (calibration) and simultaneously with the force impact.

The main products of the Aramis software processing were images (virtual objects, figures). In this study images served for visualizing strain distribution when the loading achieve intensities of 100 and 300 N. In that moment the second and the last (fourth) stages were reproduced by Aramis software thus, figures related to the second and the fourth stage, served for visualizing the results.; first stage was considered to be at 0 N, immediately after the calibration. A region of interest was assigned to the anterior part of mandibles so the section lines set by software were placed on the central position between central incisors. This line joins the points of reference placed on the

observed object, mandible and PFM restorations, and it changed its length with the changing of the load-intensity. The Aramis software itself set the reference points (parts of the section line) to calculate the change in length under control of researcher. Thus, it was possible to calculate the distance between any two points within the surface of the tested models. A stage-reference point was also set by software depending on researcher’s demands. It was determined to be at the marginal edge of the mandible beneath the restorations to highlight the real dimensional changes occurring as a consequence of the mandible-restoration interaction under posterior loading conditions. Stage point values were changing (fluctuation) through the stages. Stage point in figures presented strain value at one point of the second and the last stages. The reference points used for comparison between groups (more than two, and include stage point) were on the line section in every single figure [1].

Dimensional changes were determined within two experimental models (RPD and FPD) under vertical loading conditions. The major (principle) strain fields of the anterior regions of interest were visualized during vertical loading of the posterior teeth under forces of 100 and 300 N. It means that only the anterior abutments from left to right canine and the surrounding support bone tissue (marginal) may be well detected and thorough analyzed by the camera system. The system excluded the lateral sides of the mandible models (posterior mandible).

The scale in Figures enabled registering of quantitative changes in the anterior mandible, and it was presented in percents.

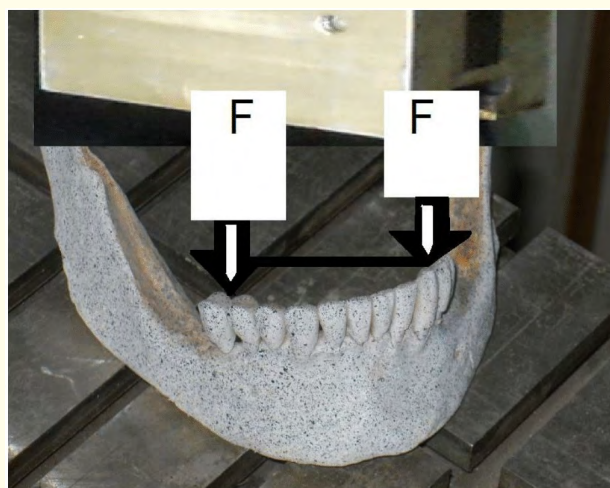
Results

The strain values of the FPD model were higher than strain values for the RPD experimental model (Tables 1). According to strain (deformation) formula $e = (L_0 - L_1) / L_0 \times 100$, where L_0 and L_1 were the lengths before and after loading respectively, the strain values were expressed in percents, and presented on the scale by different colors. Also, further individual strain values were analyzed with ARAMIS software (Table 1). For the vertical/sagittal lines (Figures 1-4), the values of strains in the anterior mandible are given in Table 1, with applied forces from 0 to 300 N, increasing gradually by 100 N. Both models (RPD and FPD) indicated higher strains in the fourth stages than in the second stages. Percentage size of the line section strains in RPD model was from 0 to 0.22%. (Table 1). Strain values linearly increased with increasing the intensity of loading. Higher strain values of the last stage in RPD model were found in the marginal bone around anterior abutment teeth, next to the line section (Figure 1, 2). These values of strain were located in only few parts of the anterior mandible and were extreme values for RPD model. Overall mean strain for the fourth stage of the anterior mandible is about 0.11% in RPD model. Percentage size of the line section strains in FPD model was from 0 to 0.5%. The highest strain was noticed in the region of marginal bone (marginal dried periodontium) just below the anterior retainers (Figures 3, 4). Strain values around the anterior abutment teeth in FPD model (0.075 - 0.5%), were higher than in RPD model (0.05 - 0.35%). Generally, mean strain value for the fourth stage of the FPD-anterior mandible was 0.28%.

Load (N)	Stage	Strain within RPD model (%)	Strain within FPD model (%)
0	1	0	0
100	2	0.07*	0.25*
200	3	0.15	0.38
300	4	0.22	0.50

Table 1: Separate strain values (strains) for both (RPD and FPD) models.

*section line shows separate strain value in the second stage of in vitro RPD and FPD models loading



Schema 1: Posterior loading of FPD model prepared for strain visualization of anterior mandible.

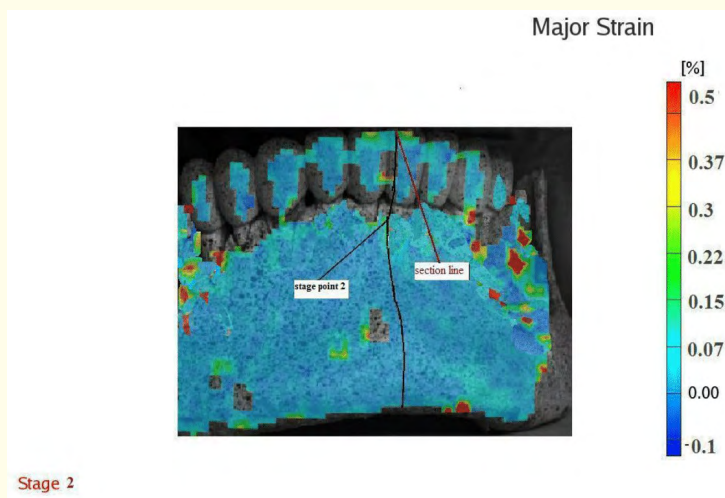


Figure 1: Major strain field in the second stage of RPD model loading.

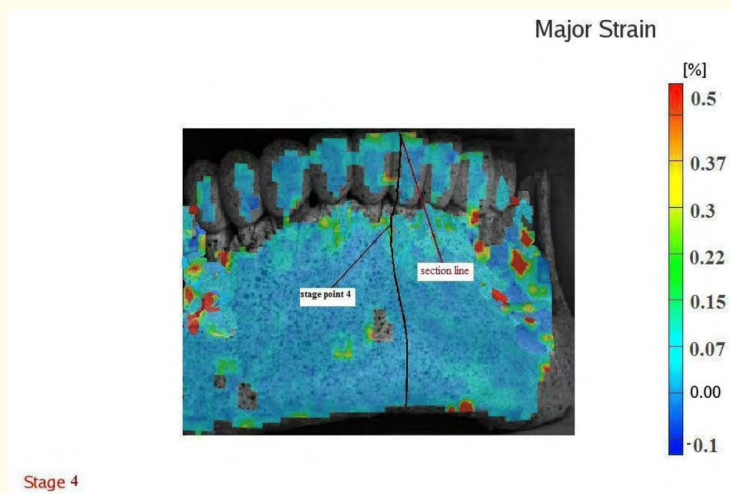


Figure 2: Major strain field in the fourth stage of RPD model loading.

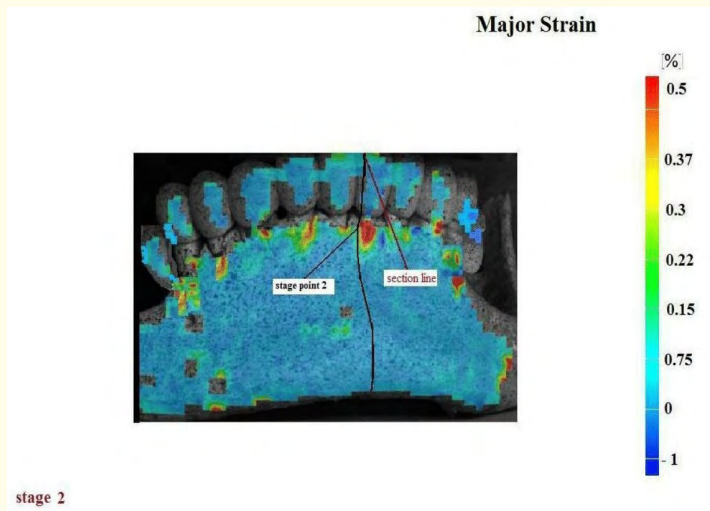


Figure 3: Major strain field in the second stage of FPD model loading.

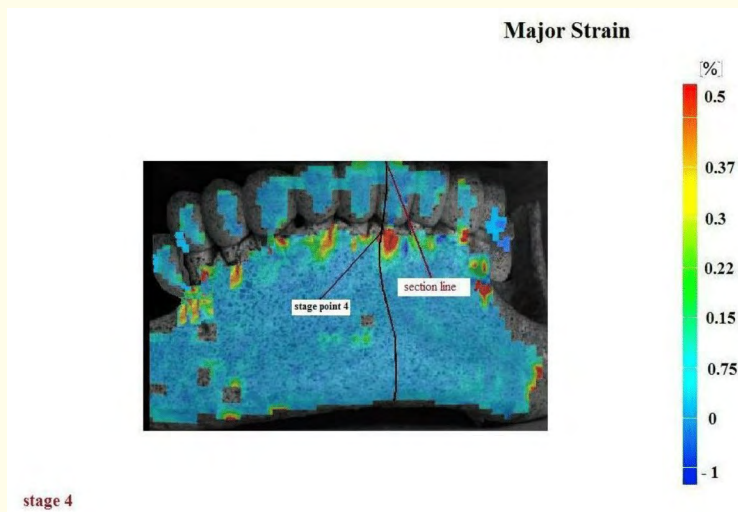


Figure 4: Major strain field in the fourth stage of FPD model loading.

Discussion

Digital image correlation method (DIC) was established to determine and measure surfaces strain generated by static non-impact loads. Two types of experimental models with different prosthetic designs were used. DIC has now been widely used in dental research due to its in sensitivity to temperature changes or largeness of the models under investigation [1,17]. On the other side, technique allow certain movements and ambient vibrations. An attractive feature is the possibility for showing local details obtained for the whole surface of the model with complex geometry under observation. This can approve and highlight this method over others, similar to the

finite element method (FEA). A limitation of the DIC technique is the fact that camera can catch only one side, of the mandible; in this study, vestibular surfaces of the anterior segments were investigated. Following a minimum technical inconsistency, limitations of this kind of experiment conducted on the cadaveric specimen – mandible were explained in previous researches [1,2,11]. Surfaces strain was qualitatively visualized as the gradient of different colors and analyzed in percents to give full insight into the biomechanical behavior of the analyzed structures.

Study presented biomechanical view of two viable therapeutic solutions placed in situ on the mandibles with shortened dental arches. Treatment modalities employed in the study indicated different biomechanical behavior for possible comparison. The upper part of the anterior mandibles (pars alveolaris) and the anterior abutments were considered. Section lines were placed on the same positions within virtual models thus, proper comparison of strain values between two experimental models was enabled.

Generally, experiments have shown higher values of strain in FPD model comparing to RPD model. Load of 100 N caused four times higher strains in FPD model than in RPD model. A linear dependence between force (load) and strain was recognized. Higher strains were probably the reason of different connections between RPD and FPD. This can be argued as the feature of attachments which allowed movement of the free-end saddles toward the edentulous ridge when loaded and consequently lesser strain in RPD model. Unlike the second experimental model where all remaining teeth were splinted in the full-arch reconstruction with cantilever FPD, the movement of RPD free-end-saddles resulted in transfer a majority of the applied load to the edentulous ridge, which led to much less strain beneath the anterior retainers (see Figure 2). The difference in strain values may be attributed to the effect of splinting remaining teeth in the experiment. The rigid construction of the cantilever FPD showed higher strain values in the anterior supporting marginal bone compared to the values found in the first experiment (RPD model). Although load transfer to the cantilever caused only limited stress transfer to distant portions of the anterior mandible (and abutments surrounding), splinting of the remaining teeth allowed uniform distribution of load to the supporting alveolar bone. However, it was shown that the bone underlying the FPD undergoes a higher resorption, which is in correlation with findings of Field C., *et al* [18]. FPD therapy influenced higher strain magnitude on the marginal bone of adjacent anterior abutments when loaded the distally extended units. Actually, in the case of connecting two or more teeth rigidly (PFM bridges), loading is distributed and transmitted to both or each single abutments (and retainers) [19,20]. The effect of connecting teeth seems to be limited locally due to direction of the principal strains was within the upper part (marginal bone) of the mandibles. Thus, when strain pattern for both models were compared the FPD loading did not induce significantly higher overall strain of the anterior mandible, although higher strains within the marginal bone were registered next to FPD abutments than to RPD abutments. Higher values of strain in the marginal bone of FPD model emphasize the importance of avoiding pontic only loading due to existed lever mechanism [1,2]. Additionally, attachment retained RPD is less rigid than cantilevered bridge and therefore it will have greater mobility and so doesn't require higher rate of the anterior bone tissue support. In contrast the rigidity of cantilevered bridge was higher and needed stronger bone tissue support.

Based on the aforementioned, the clinicians have to consider periodontal status of remaining teeth especially if we are guided by one of the dogmas in prosthodontics which says that therapeutic success is correlated with the planning of the prosthetic design. Accordingly, cantilever FPD may not provide the best biomechanical solution on periodontally compromised abutment teeth due to their possible overloading during masticatory functions. In such cases, properly designed and adjusted RPD with fixed splinting of remaining teeth might be considered as therapeutic option. Although, in situations with diminished periodontal support extensive full-arch splinting may not be effective or appropriate when using RPD [20].

Conclusion

Strains in the anterior segment of the human cadaver mandibles restored with different therapy modalities were assessed using digital image correlation method. The optical method used in this study visualized strain distribution in the mandible models during occlusal loading. Within the limitations of this study, the following conclusions were derived:

- Higher strains of the marginal bone tissue in the anterior mandible were observed during loading of the FPD model;
- Strains within marginal bone area were mostly influenced by the teeth and denture vertical displacement;
- There was existence of linear dependence between the force (load) intensity and strain in both experimental models.

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Conflict of Interest

There are no conflicts of interests, financial or otherwise associated with this work.

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