

Biomechanical behavior of restored and unrestored mandible with shortened dental arch under vertical loading condition

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The aim of this in vitro study was to investigate the strain distribution of the compressed mandible bone under the applied restoration-removable partial denture and to compare with the same but unrestored mandible under vertical (occlusal) load and to find out whether removable partial denture-restored or unrestored mandible causes greater strain effect on supporting tissue. Four mandible models were tested during loading for the purpose of strain measuring. Digital image correlation system (GOM – German Optical Measuring, Braunschweig, Germany), used for measuring strain consists of two digital cameras and software ARAMIS (6.2.0, Braunschweig, Germany). Remaining teeth suffer from greater strain in the mandible model without removable partial denture (7.5–10%). On the contrary, mandible with removable partial denture shows the maximum strain below the denture saddle (3.5%). However, it can be noticed that the marginal bone of the second lower premolar in both experimental models is deformed whether the mandible model has (2.8%) or has not (10%) replacement. Within the limitations of this study the higher strain is observed in mandible model without replacement and the strain is limited locally, in the bone region that surrounds remaining teeth and mental foramen.

Key words: shortened dental arch, removable partial denture, strain

1. Introduction

Shortened dental arch is defined as the condition where most of the posterior teeth are missing [1]. In the current dentistry very pertinent and common problem is whether this condition has to be treated or not. For this reason many schools and researchers dare to talk about the ideal treatment for the case of shortened dental arch [2]–[12]. Some of them are guided by the idea that the lack of posterior teeth is not necessary for an ideal occlusion and mastication. They claim that 20 well-preserved remaining teeth are enough for healthy masticatory function and daily food intake [13]–[16]. The other opinion is that only the presence of all 28 teeth enables satisfactory and sufficient nutrition without TMJ disorders [17]–[19]. According to that, some authors propose a conservative prosthetic treatment (removable partial denture –

RPD) in order to replace missing posterior teeth and improve masticatory performance [17] and life standard [20]. Although the addition of the posterior teeth through RPD using may result in an easier and faster chewing process and better swallowing of the chewed food [17]–[19], the biomechanical effect of RPD restoration on the supporting hard tissue during mastication is not clearly understood and yet to be analysed using available methods for strain measurement. In dentistry, strain measurements have been restricted to non-invasive methods that measured bite forces on patients and strains in experimental models [21], [22]. One of the most attractive techniques is digital image correlation method (DIC). For biomechanical research, DIC is an optical measurement system often used for in vitro set-ups [23]–[25]. DIC is an optical full-field technique for non-contact, 3D deformation measurements [26]. In this research, DIC was used to determine strains on the mandible surface during

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loading process. The following study is an optical analysis of the biomechanical behaviour of the restored and unrestored mandible with shortened dental arch (Kennedy class 1).

The aim of this *in vitro* study was to investigate the strain distribution of the compressed mandible bone under the applied restoration-removable partial denture and to compare it with the same but unrestored mandible under vertical (occlusal) load, and to find out whether RPD-restored or unrestored mandible causes greater strain effect on supporting tissue.

2. Materials and methods

Four dried mandibles were used for the purpose of strain measuring. The mandibles were borrowed from the Laboratory for Anthropology, Institute of Anatomy, School of Medicine, University of Belgrade for the purpose of the experimental analysis. The donors were men, late fifties from Serbia. In the selection criteria of mandibles it was necessary to fulfil conditions in which mandibles are without traumatic and pathological damages found in obduction with the absence of the posterior teeth, molars.

A mandible with full (intact) dental arch, a complete edentulous mandible and two Kennedy class 1 mandibles with bilaterally shortened dental arch (experimental models) were previously left to stay in the physiological solution (0.9% NaCl) in order to reach the volume and elasticity to withstand the applied loads [27]–[29]. After drying the bone surface layer at a temperature of 27 °C the, mandible with full dental arch – FDA reference model (figure 1), and Kennedy class 1 mandible without replacement, shortened dental arch – SDA model (figure 2) were ready for testing, but the other two mandibles had to be prepared. Edentulous mandible was then used for manufacturing the complete acrylic denture through the impression procedure with elastomers in standard tray, so the restored edentulous mandible with complete acrylic denture positioned *in situ* (figure 3) was obtained (complete denture – CD reference model). One of the two experimental models of Kennedy class 1 mandibles was served for the acceptance of removable partial denture – RPD model (figure 4). Following preparation of the abutment teeth, a conventional RPD with cast circumferential clasps (clasp-retained RPD) in combination with full coverage cast PFM crowns on the remaining teeth was made.

Before the experiment the surfaces of all four mandible models were sprayed with a thin coat of white layer paint, followed by a thin layer of high contrast black paint placed on top of the white layer to allow the correct performance of the digital image correlation (DIC) method.



Fig. 1. FDA reference model



Fig. 2. SDA experimental model



Fig. 3. CD reference model

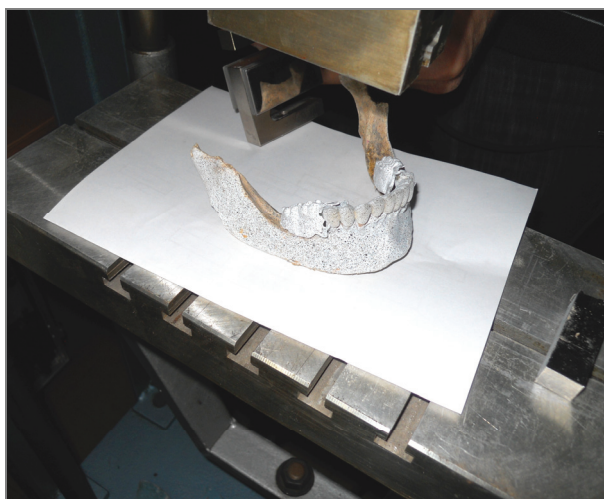


Fig. 4. RPD experimental model

Reference mandible models, SDA mandible model and RPD mandible model, were exposed to the force of 300 N. The applied load was vertical and was positioned on the buccal and lingual cusps (figure 5) on the last remaining natural (FDA reference and SDA model) or artificial (acrylic) tooth essential for the mastication process (second molar of the CD reference model) and last artificial tooth (second molar) of the removable partial denture placed in situ – RPD model. The first lower molar is the key of occlusion so the load applied on this tooth, in physiological condition, may extent to 500–700 N. Thus it was much appropriate to use second lower molar as the point of attack to equalize the force intensity acting upon the second praemolar and second molar.

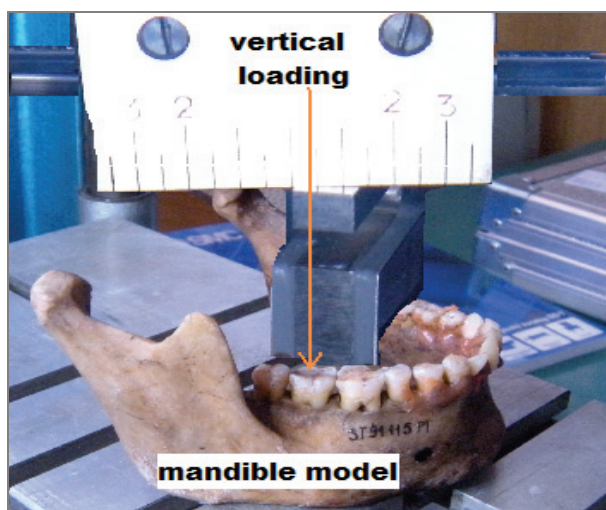


Fig. 5. Buccal and lingual loading position

Digital image correlation system (GOM, Braunschweig, Germany), used for measuring strain consists of two digital cameras and software ARAMIS (6.2.0,

Braunschweig, Germany). A schema of the measuring system is presented in figure 6. The applicability of this system has already been described in earlier studies [30], [31].

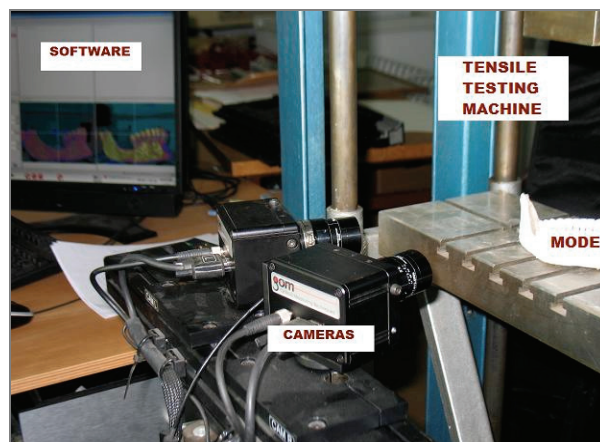


Fig. 6. Optical measuring system

3. Results

This study includes only the upper part of the mandible bone, so it presents the results of the bone adjacent to the posterior teeth and local anatomical structures. The highest strain is detected in the second reference model – CD model with the peak strain of 18.94% (figure 7). Similar behavior between two restored and the two unrestored mandible models was observed. Percentage size of the FDA reference mandible strain was from 0.029 to 0.45% (figure 8). According to data represented on the figure scales (figures 9, 10) the higher strain values are noticed in the SDA model (0–10%) compared to RPD model (0.2–3.5%).

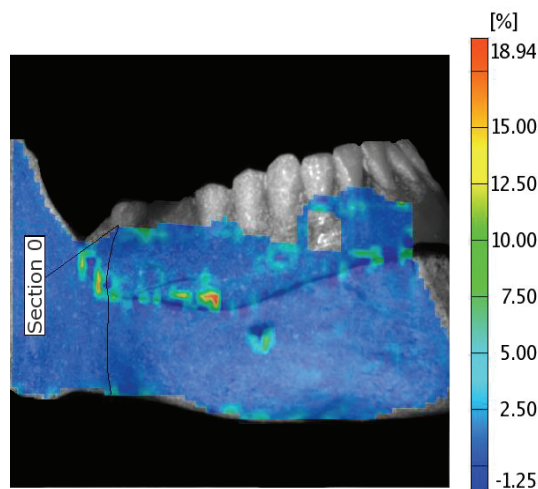


Fig. 7. Virtual CD mandible model

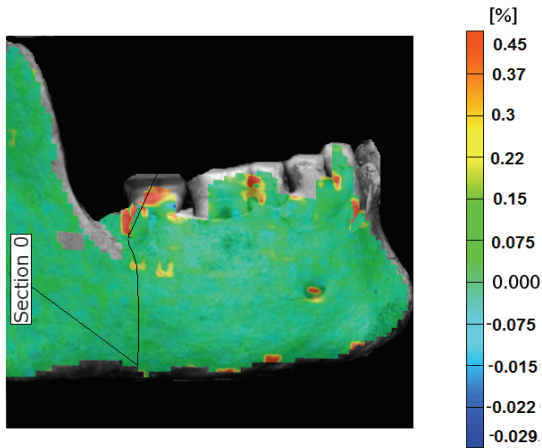


Fig. 8. Virtual FDA mandible model

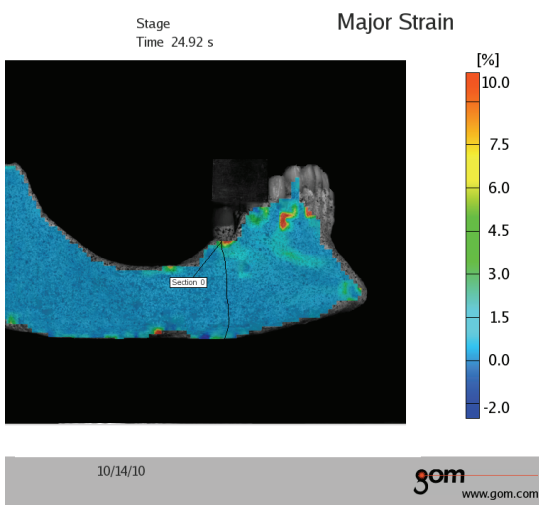


Fig. 9. Virtual SDA mandible model

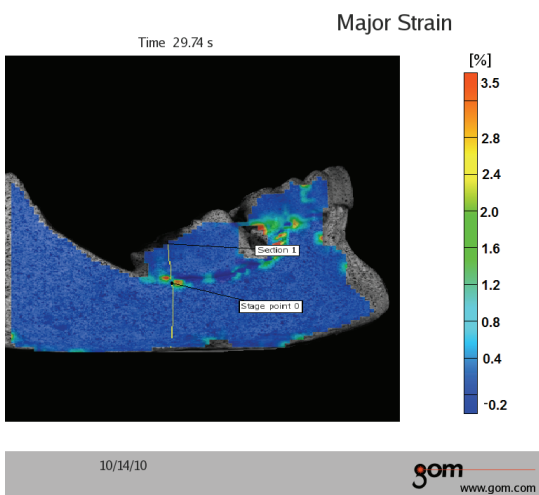


Fig. 10. Virtual RPD mandible model

Residual ridge of both restored, CD and RPD models and the marginal bone of the dried periodontium that surrounds loaded teeth of both unrestored, FDA and SDA models are the bone areas that accumulate

a large shear of the applied load. Both, CD reference and RPD experimental models show the highest strain just below the denture saddle (15% and 3.5%). SDA model indicates greater strain within marginal bone visualised from the right vestibular site of the mandible (7.5–10%). The vestibular laminae of the posterior abutment within RPD model indicates greater strain (2.8%).

Local area of the jaw bone surrounding the posterior teeth also suffers from certain strain, which is probably the reason of different strain propagation within different mandible models. It has been noted that mental foramen and trigonum retromolare deform to a greater extent in all three virtual models. Higher strain of the mental foramen is detected in the SDA model. When it comes to trigonum retromolare, the highest strain is registered in the RPD model.

4. Discussion

Generally, *in vitro* studies can provide better prognosis in clinical practice. The experiment is performed based on the fact that dental biomechanics is an interdisciplinary approach in which engineering principles are applied to dentistry. By using this optical system strain of complex structures, such as mandible bones and replacements, under different conditions can be measured with high accuracy [30]–[34]. Moreover, photogrammetric techniques, with high resolution CCD cameras and modern data processing systems, have the advantage of producing a large amount of experimental data [35], [36].

Four compressed mandible models (real models) indicate differences in strain distribution which is presented in every single virtual model (figures 7–10). Figure scales present the amplitude of strains in percent. According to figure 9, SDA model has the highest strain distributed on the remaining posterior teeth. Although the results of strain measurement are obtained for the case of single tooth loading, the full strain field can reproduce the majority of strain propagation through the entire dried periodontium and mandible bone viewed from the lateral (buccal) side. The average strain represented in figures 7–10 is the result of compressing the same models at two points, simultaneously buccal and lingual cusps.

Reference model is used to determine the overall paradigm of the mandible behavior during loading. It is noticed that all four models show strain in the mental foramen and trigonum retromolare. Dominant strain of the mandible models was in the area of applied load, and with moving the point of loading

the size of the strain is changing. Anterior shifting of the load position causes greater strain in the mental foramen (figure 9). On the contrary, posterior shifting of the applied load has a stronger effect on trigonum retromolar (figures 7, 8 and 10). FDA and SDA models demonstrate higher strain within marginal bone that surrounds loaded teeth (second premolar and second molar). The average strain is still significantly higher in the SDA model than in the FDA or RPD model (figure scale). The reason for this strain distribution lies in the presence of a fewer number and lesser volume of the roots of lower premolars in relation to the massive and two-root molars [37]. This can mean a more even (uniformly) transfer of load within FDA reference model. Previous studies indicate that higher displacements and strains of bone tissue are observed below the RPD, especially in the region of the distal abutment and distal portion of the free-end saddle [31], [38], [39]. The above-mentioned fact is also confirmed by this experiment. Nevertheless, the maximum strain is lesser in RPD model compared to SDA model. It is also noticed that loaded RPD model induces high strain in the region of the residual alveolar ridge, which is similar to the direction of strain propagation obtained in the case of loading the CD reference model. Oposite to CD reference model, RPD experimental model shows significantly lower mean strain value which is supported by the fact of dual (bone-abutment) transfer of the applied load compared to the “bone only transfer” within CD model. Inversely, loaded SDA model visualizes high strain in the marginal bone of the remaining teeth during the same intensity load. Under the applied forces appearing it may be said that strains within mandible models are mostly influenced by the teeth and denture vertical displacement [40].

Currently, it can be argued that from biomechanical viewpoint both treatments can be equally used in the patient with bilaterally shortened dental arch. Maybe, an adequate design of RPD positioned on splinted PFM crowns for patients with periodontally compromised remaining teeth is better choice than SDA therapy concept.

5. Conclusion

Within the limitations of this study it has been found that:

- higher strain is observed in SDA model and the strain is limited locally, in the bone region that surrounds remaining teeth and foramen mentale;

- RPD model mostly deforms in the region of the residual alveolar ridge and distal abutment.

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