Visualizing Strain Behavior of Mandibles with Gradually Reducing of the Permanent Teeth Using Digital Image Correlation Method

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Abstract

In dentistry, masticatory forces are applied to tooth crowns in dental occlusion and normally transmitted to the surrounding bone whether mandible or maxilla. Deformation of mandible depends on the properties of the material bone, especially its mineral content and porosity, the muscles and the mandibular form. Deformation can be thorough estimated using different methods. The goal of this study was to analyse the surface micro-displacements of lower jaws with gradually reduction of the permanent teeth. A total of 3 mandibles (lower jaws) were removed during autopsy (3 males, and aged between 45 and 55 years, mean 50 years). First mandible model had intact dental arch; second model was determined by bilateraly missing molars while the third mandible model was the model with absence of posterior teeth. After preparation, mandible models were placed in the standard press system-tensile testing machine where were tested. Software used in this research, ARAMIS is the optical, contactless, measuring system based on the principle of objective raster (fine-ground) procedure. The method for full field measurement of strain was done by using the ARAMIS three-dimensional image correlation system. The results of this study showed that the intensity of strain values increased with the anterior shifting of the force acting. The highest strain was found in the marginal bone of tested teeth in all three experimental models.

Keywords: Mandible; Occlusion; Digital Image Correlation Method

Introduction

Objects loaded by an external mechanical load (tension, compression, bending, etc.) experience stress and strain with spatial distribution throughout an entire object. During mastication loads are applied to tooth crowns and transmitted to the surrounding bone [1]. Several studies on dental occlusion have investigated the displacement and deformation patterns in the periodontium (tooth, alveolar bone, periodontal ligament) [2,3-5]. These studies highlighted very important role of periodontal ligament for receiving masticatory forces and distinguished a possibility for subsequently deformation of the alveolar bone to generate strain. Such a biomechanical behavior of bone depends upon the properties of the material bone, especially its mineral content and porosity [6] and can be estimate using a digital image correlaton method (DIC). In this work, it was preferred to choose the DIC method for strain analysis to validate previously mentioned, since this method can provide a full view of deformation fields in an entire region of interest [7]. Using DIC, it is possible to create a model of a whole bone, and then experimentally test the same bone under conditions identical to those simulated in the numerical analyses. Although much effort has been devoted to numerically understanding the mechanical behavior of individual constituents [8,9-11], there is a lack of full dynamic pictures of more realistic deformation patterns of the entire periodontium and bone, which is essential for complete understanding of the tooth movement and then underlying mechanisms of the tooth damage, bone loss and bone remodeling phenomenon.

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The goal of this study was to analyse the surface strain of mandibles with gradually decreasing of posterior teeth using the DIC method.

Material and Method

A total of 3 mandibles (lower jaws) were removed during autopsy (3 males, and aged between 45 and 55 years, mean 50 years). Dried mandibles were borrowed from the Antropology laboratory Institute of Anatomy, School of Medicine, University of Belgrade. First mandible model had intact dental arch, second model was determined by bilateraly missing molars while the third one was the model where only the anterior teeth left. This means that the models were chosen based on criterion of the gradual shortening of the dental arches, starting from models with full dental arch. The models did not show any bone disease, neither in relation to the cause of death nor from the findings during autopsy. All the deceased had given permission prior to death that the body or parts of it could be used for scientific investigations. After removal, the mandibles were thoroughly cleaned of the soft tissue covering. Prior to each series of experiments the mandibles were immersed for 1 h in 0.9% sodium chloride solution to improve the elasticity of the bone [12]. After drying at the temperature of 27 Celsius degrees, jaw-bones were lacquered with a white and great density spray. After preparation, mandible models were placed in the standard press system (tensile testing machine). The press system was measured the bone deformities of the experimental models. In the experiment were applied forces of 0 to 300 N. The load was directed to the central fossa of loading (testing) teeth, across the horizontal extention of the gnatodynamometer which was used for the purpose of the controlled force measuring. Testing teeth were: the right lower second molar (first model), the right lower second premolar (second model) and the right lower canine (third model). Load was applied on surfaces of teeth to simulate the central occlusion position. This position is the most common in human population and only during swallowing is repeated 800 times a day. Measurement of strain was done using equipment manufacturer GOM (Germany). System is composed of two digital cameras and software ARAMIS. Mobile cameras photographed the distance between points before the load in the calibration phase, and later, during the action force. Before the experiment was started, the calibration was done. Calibration procedure is a calibration system for setting all parameters. By calibration the dimensional consistenceis provided in order to get the precise results of measuring. The camera positioning on the stand was done manually according to defined parametres in advance. For 3D measuring, two cameras were used and adjusted in accordance with the measuring volume by the calibrational object. The choice of the measuring volume dimensions directly depends on the measuring object dimensions. By choosing the measuring volume the distance between the sensor and the measuring object was determined.

Software that was used in the research, ARAMIS is the optical, contactless, measuring system which is based on the principle of objective raster (fine-ground) procedure. It serves for measuring (estimates) three-dimensional changes of shape and distribution of deformities on the surface of statically and dynamically loaded objects. With high accuracy and contactlessly, ARAMIS determines the shape of the filmed object, its dimensions, the field of three-dimensional movements, the vector distorted field and the features of the biomaterial. ARAMIS separates the superficial layer of the tested bone 2 mm thick and shows distorted fields over the whole surface of the filmed bone, which means that only the part of the bone the camera spots is analysed by ARAMIS. The surface of mandibles has to be prepared by putting the fine layer of the dispersive colour with expressive contrast. The fine graing of this spray occupy certain mutual distances which are changed under the force and it is registered by cameras [13 14].

Results

The major (principle) strain fields (Figures 1-3) were obtained during the central fissure loading of 300 N on the right second molar, right second premolar and right canine of the lower jaws, respectively. The section line, set by software, joins the points of reference placed on the observed objects, lower jaws. The section lines presented in this study were changing the lengths in accordance with changing the intensity and the position of the ''force-attack'' points. Figures have shown the section lines of the last stage of the bone strain under the force intensity of 300 N. The scale (Figures 1-3) enabled registering of quantative changes in the mandible presented in percents.

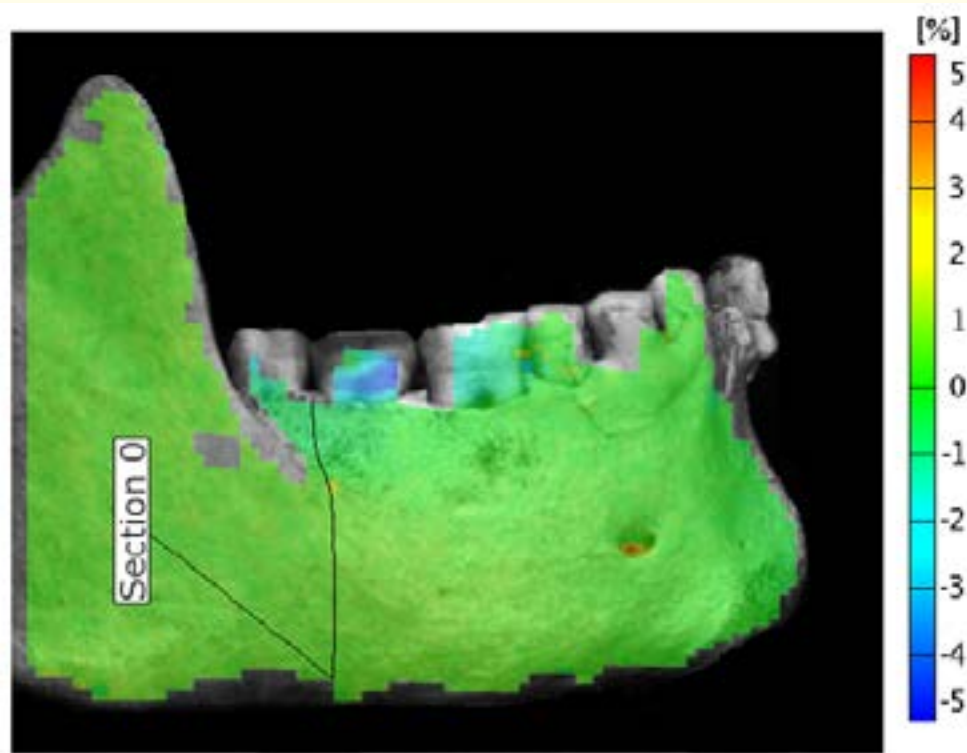**Visualizing Strain Behavior of Mandibles with Gradually Reducing of the Permanent Teeth Using Digital Image Correlation Method**

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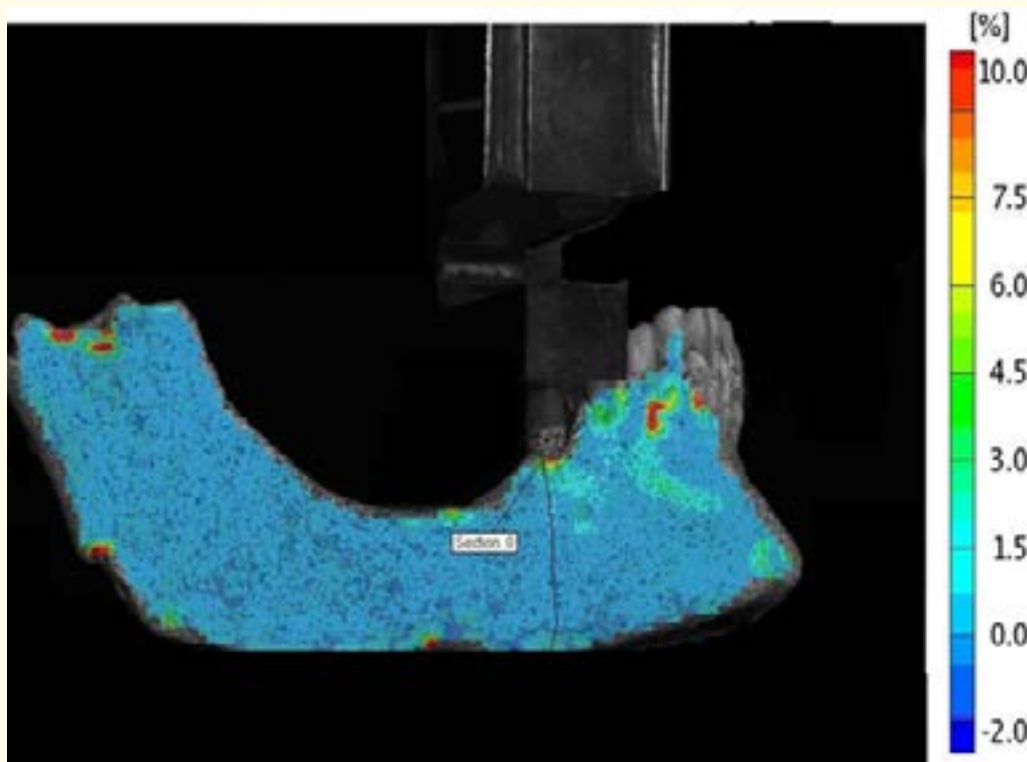*Figure 1: Strain in mandible detected during lower molar loading.*

Figure 2: Strain in mandible detected during lower premolar loading.

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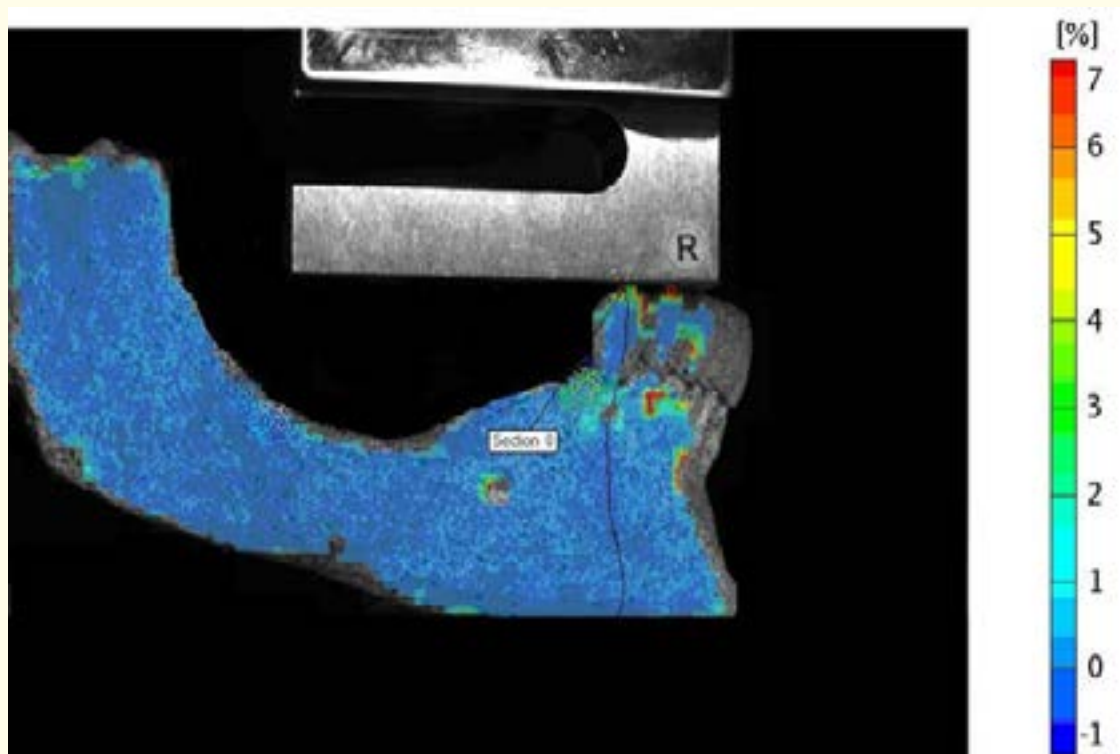
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Figure 3: Strain in mandible detected during lower cannine loading.

Percentage size of the first experimental model (lower jaw with intact dental arch) deformations were from -5 to 5%. Marginal bone of the tested tooth showed the lowest strain value (up to 1.50%). The major strain field of the other part of lower jaw bone fundament indicated the color uniformity with uniform distribution of strains within the jaw bone tissue and mean strain value of 0.5%.

Second part of the experimental analyse includes loadinig of right lower second premolar. Strain field showed the most intensive deformation in the region of marginal bone surrounding the tested tooth (7.5%). Also, deformations were found within the bone aperture (foramen mentale) with the strain value of 1.7% and distal alveolar part of edentulous bone saddle (6%). Deformations of the right first lower premolar and anterior teeth (1.5 - 7%) can be noticed in the upper part of mandible body.

The last part of the experiment was related to canine loading. Deformations were found in the bone tissue that was in direct contact with the tooth (2 - 3%) as well as in the bone of the adjacent anterior teeth, closest to cannine tooth (to 6%). The mean strain value of the foramen mentale was about 1.5%. Figure 3 shows the distribution of deformation changes in the elastic strain field (major strain field), and the scale beside the figure describes intensity of deformation in the percentage.

Discussion

The advantage of 3D optical measuring is the ability for registering bone lamellas micro-displacements by direct observation of the segments with the shortened interval of obtaining the exact results, without scanning with high accuracy and repeatability [15]. Its main disadvantage compared to other methods is its lower sensitivity determined by the field of view that does not exceed 0.3 microns [16].

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Additionally, this method is limited with the fact that only one side of specimen has been viewed by cameras. The study included only the right part of the mandible models viewed from sagittal (lateral) aspect where left side of the lower jaws was excluded. Additionally, the curves of the tested mandibles, can not be analyzed thoroughly. The abovementioned may reduce the resolution and maximum accuracy of the images. The cameras can catch only the flat surfaces with high precision. Thus, validation of strain would be very questionable if the entire surfaces of mandibles were interpreted. Like other cadaveric analyzes this experiment may suffer from the donor-related variability of the investigated mandibular speciemens, the absence of soft tissue coverage and impossibility of positioning mandible as in real situation where muscles are involved. Nevertheless, this type of study, analyzed with DIC, could help us to understand the nature of the strain distribution through the hierarchical structure of mandibles with different dental status. The presence of the soft tissue was avoided in this research, thus the viscoelastic properties of the periodontal ligament (PDL) and mucosa layer were excluded in methodology. Knowing dimensions and physical characteristics of the mentioned structures it was considered that these structures can not change the visualization of the overall strain, unless if we were not considered quantitatively changes [17,18]. What I was interested in was not the absolute but relative values of strain, which was obtained with the help of the digital camera and ARAMIS software, by tracking the relative extensions between featured points painted on the surface. Strain values were presented qualitatively as gradient of different colors and analyzed in percents, in order to give full insight into the biomechanical behavior of the analyzed structures [13,14].

The highest strain was found in the marginal bone of the tested teeth in all three experimental models. It seems like the maximum strains were located just below the attack points. Generally, overall strain was higher in the second and third experimental models. By evaluation of the experimental results it can be noticed that under the same force action, deformations in the region of the second lower premolar and canine were more expressed than deformations in the region of the second molar. So, the results of this study show that the intensity of strain values increase with the anterior shifting of the force acting. The reason for this kind of the strain distribution lies in the presence of the fewer number and lesser volume of the roots of lower premolars and cannines in relation to the massive and two-roots molars. Strain were higher below premolar than canine probably because of the largeness of the canine's root compared to premolar. Nevertheless, strain was very high arround anterior teeth when the canine was loaded. Thus, the part of the load was actually moved from canine's periodontium to tiny bone arround incisives.

Another segment of discussion is adress to deformation of anatomical structures such as foramen mentale. Research has shown that the maximum strain of the foramen mentale has found during second model loading. It is assumed that the short distance between aperture and premolar was the reason for high strain below this tooth. Regularity in the concentration of deformation exists in terms of higher accumulation in the same bone lamellas that were in direct contact with the tooth that was exposed to the masticatory forces, and in the region of foramen mentale, especially in the second and third model. All major strain fields show oval storage segments that were much more expressed in the upper parts of the jaw-bone (*pars alveolaris mandibulae*).

Conclusions

In accordance with the aim of this research strain of 3 mandibles was measured and recorded using the DIC. By analyzing the test results can be drawn the following conclusions:

- When loading the lower jaws, the distribution of strain through the lower jaw bone system was uniform.
- The Highest values of strain were recorded in the lower jaw bone that was in direct contact with teeth that burden, and the bone regions of foramen mentale.
- Higher values of strain were observed with the anterior load shifting.

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